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Evaluation the influence of aerator ramp on reducing the cavitations risks in Shafaroud, Azad and Gotvand dams

Zahra Parhizkar[1], Amir Khosrojerdi[2]
1- M.S. Student of Hydraulic Structures Engineering, Islamic Azad University, Science and Research of Tehran
2-Associate Professor in Department of Water Science and Engineering, Islamic Azad University, Science and Research of Tehran Email ID : zahra.parhizkar.88@gmail.com

Abstract - Current weather indifferent fields of science and engineering research purposes and different applications are studied. One of the applications of climate studies, the study of the flow over the weir dam and lower exhaust tunnel is aimed at preventing the risk of cavitations. Aeration is known as one of the most economical and practical way to deal with cavitations on rapid spill ways. In the study of the phenomena of cavitations and aeration systems, three dams on Iran to prevent this phenomenon from a physical model including dam spillway such as Shafaroud, Azad and Gotvand are investigated. According to the result sofa single Shafaroud dam spillway, aeration system has little effect on reducing the risk of cavitations. In the Azad dam spillway, using two aeration systems as the first option, and in the Gotvand dam spillway, using three aeration systems as the first and second choices in both channels was the best options of aeration. According to the conducted studies by comparing the performance of aerator ramp in Azad and Gotvand dams led to acceptable results. Thus, in comparing the performance of aeration systems of these two spillway dams, we can say with lower (values of height to horizontal length ratio of the ramp (a/b), the maximum horizontal length of jet from the aerator ramp, chute angle and the height difference between the beginning and end of the spillway) and higher (height and horizontal length of the aerator ramp), the aeration efficiency will be the best.

Key Words – Chute spillways, cavitations, aeration.

1. INTRODUCTION

Spillways are the most important part of a dam that plays important roles in avoiding additional floods with long return periods. One of biggest problems in large spillways is cavitations which usually flow speed in a part of a hydraulic part exceeds a threshold, that part is at the risk of cavitations. One of the probes that are used to locate the probable is the place of cavitations in spillways which is comparing the cavitations flows number (coefficient) and cavitations crisis number. Calculating the Cavitations number by using air pressure and computational or calculated flows speed for different discharges in all chute range is the same as below:

$$б = \frac{(\frac{P_{Atm}}{\gamma}) - (\frac{P_v}{\gamma}) + h\cos\theta}{v_0^2 / 2g} \quad (1)$$

In this equation:
(P_{atm}/γ):is surrounding pressure that is equal to one atmosphere or 10.33 meter of water column in laboratory condition.(P_v/γ):is amount of steams pressure of liquid which is approximately 25 degrees and it's equal to 0.33water height(m) . In calculation due to ensure factor this considered as 1 meter of water height. H cosθ or $(p./\gamma)$is measured as pressure on different parts of the structure.$(v.^2/2g)$ is height matching speed (in meters)which is in specified area. By replacing mentioned numbers in the last equation, we have following equation which the conditions of studied spillways are based on this.

$$\sigma = \frac{((10.33-1) + p_0/\gamma))}{v_0^2 / 2g} = 2g / v_0^2 (9.33 + p_0/\gamma) \quad (2)$$

Comparing the critical cavitations number and flow cavitations number shows that places which flow cavitations quantity is less than critical cavitations number, because of cavitations risks. According to recent equation cavitations, the limitation for mentioned dams is 25220 in average .Following the USBR studies if cavitations number exceeds 022 cavitations probability is low and if it gets over that, the cavitations probability goes high. Recent experiences show that if cavitations number is between 021 and 022, existence of aeration system for preventing possible cavitations damages is necessary and if cavitations number is less than 021 spillways, it should be designed later. Aeration is one of the most practical and economical methods for avoiding and decreasing dangers of cavitations. Exact mechanism of cavitations prevention by aeration is not well known properly but tests show that, injection of

8% air in flow's environment could avoid cavitations damages completely. For aeration in flow's way we can place a ramp, step or a hole or a combination of all. Any of these aerators are creating a jet of air from the inside of the upper and lower surfaces. In Iran, water researches institute studied probability of cavitations on a number of important dams of the country with modeling spillways of them and in some cases used the advantages of aeration to reduce cavitations damages. One of the case studies had done in 1384 which was about affection of horizontal scale in measuring flow specifications in both aeration and non-aeration situations which was led to these results: generally minimum effect of horizontal

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scale in no aeration mode on flow's parameters happens in some ending parts of the chute with bowl-shaped throwers and maximum amount is in location of aerator and entrance of air. In 1387 about affection of legs of head of spillway on specifications of flow on spillway in aeration and no aeration situations led to these results: In no aeration mode affection of legs on bowl thrower is minimum and the most affection of legs was on head of spillway. With aeration more changes was seen on end of chute of spillway and on bowl shaped thrower.

In 1389 sensitivity of artificial aeration to geometric and hydraulic parameters was researched by changing geometric specifications of spillway in physical model of Azad dam and amount of entered air into the water for different hydraulic specifications of flow studied and we found that aeration coefficient is very sensitive to length of ramp and depth of flow. After that the most sensitivity is Froude and Euler numbers and for slop of chute and slop of ramp sensitivity is minimum.

2.DATA AND MATERIAL

The process of doing this is to use experimental data WRI, The first model to be built, it is passed through the flow and measurements (including water depth, velocity, flow rate and pressure) are performed to calculate the coefficient of cavitations. Then the correlation coefficient of the critical cavitations and aeration of the system installation is necessary.
The aeration system must be installed first and critical cavitations coefficient calculated by taking the Froude number is to overflow the dam. After aeration system installed at selected distances from the overflow threshold (especially the location of aeration systems) to re-calculate the coefficient of cavitations and aeration systems and installing efficient or it hasn't realized. The risk factors include: Ramp dimensions aerator, aerator ramp horizontal overflow threshold, the maximum length of the jet aerator launch ramp, along the horizontal overflow weir height difference between the beginning and the end of the ramp angle and shot the aeration efficiency of the method.

3. RESEARCH METHODOLOGY

3-1- Azad dam

Azad dam is located in 70th kilometers of Sanandaj-Marivan. The rock fill dam with clay core with them 125 height, crown length of 600 m, the diversion tunnel and a storage volume of300millioncubic meters of water and is located1475mabove sea level. Spillway of Azad: balance of beginning of spillway is 1465 meters and impure width is 30 meters and peak curve follows this equation: [$y = 0/0584x^{1.85}$].Heightdifference between beginning and the end of the spillway is 77.5 meters and horizontal length of spillway is 264.7 meters.

3-1-1 Components of aerator system

According to Figure (1) the overflow threshold distance rangem4/184launchertostartthe corrosion rate is below the critical line [δ<=0.2].In surface cover of chute two aerators in horizontal distance of 165 meters and 210meters from beginning of the spillway is defined.
Aerator ramp height is 0/5m and the edge of the ramp angle is about7 degrees to the horizontal tunnel floor and the height of ventilator is 6.82m. [1] Here in the aeration system if the height of the ramp considered with(a) and horizontal length of the ramp shows with(b)
Therefore we will have this equation:

$$\frac{a}{b} = \frac{0.5}{3.76} = 0.13$$

After installing aerators and measurements during the first jump is determined by the length of the first jump of the aerator which is m 24.The maximum horizontal jump from the first aerator to the beginning of the spillway is 189 m. the second aeration weir is installed at distance of210m from the threshold. The maximum length of horizontal jump from the first aerator to the place of the second installed aerator is 21m. The horizontal distance between the first and second aerator is about 45m.thehorizontal distance between bowl shaped thrower and first aerator is:274.53 – 210 = 64.53 m.
Maximum length of jump from the first aerator is 24 meters and from the second one is 57 meters. Maximum horizontal length of jump from 1st aerator to the beginning of bowl-shaped thrower is: 274.53–189=85.53m.Maximum horizontal length of jump from 2nd aerator to beginning of bowl-shaped thrower is: 64.53 – 57 = 7.53 m.

3-2 Gotvand Olya dam

Gotvand dam is located in Upper Karun River in the extreme distance of 380kmfrom the mouth of the Karun River and is situated near the Gotvand town. Gotvnd Olya reservoir dams is the second largest reservoir dam after Karkheh, it's the largest reservoir tank near the Karun River also it is the largest soil dam and contains longest and largest water tunnels among dams of the country.
This dam is made of gravel with clay core that has 182 meters height and 760-meter length on head and 17 meters width of head which balance of it, is about 246 meters higher than the ocean surface. Spillway with balance of 218 m of ocean's surface has four entrances with 15 m width for each. Chute has 2 flows, which are separated with a wall which is located on one line with middle leg of spillway.

3-2-1- Parts of Aerator System

The aeration system on sharp water flow coverage include three horizontal distances which are significant in right side: 195, 255 and 355 meters ahead on the right channel and the spill way aeration system at three horizontal distances of 195, 255and380m from the threshold of the over flow tube on the left side.

During the height of the horizontal canal right aerators ramps are:

Firstaerator: $\left(\frac{a}{b}\right) = \frac{0.98}{10} = 0.098,$

Second aerator: $\left(\frac{a}{b}\right) = \frac{0.64}{10} = 0.064$,

Third aerator: $\left(\frac{a}{b}\right) = \frac{0.52}{5} = 0.104$

After installing aerators first jump will be determined during the measurement. Maximum aeration during breaks from the first is 26.5m, therefore maximum horizontal distance of jump from first aerator from the beginning of spillway is: 195+26.5=221.5
Second aerator is installed 255 meters away from beginning of spillway. It means horizontal distance of maximum length of jump from first aerator to installation place of second one is:
255–221.5=33.5.in the other words horizontal distance of first aerator and second one
255–195=60 meters which is a appropriate distance. Maximum distance of jump from the second aerator is 50 m, although horizontal distance of maximum distance of jump from second aerator at the beginning of spillway is 255+50=305 m. Ata distance of 355m from the threshold of the third aeration weir installed. It means horizontal distance of maximum horizontal length of jump from the second aerator to third one is 355–305=50 meters. Thus horizontal distance between second and third aerator is 355–255=100 meters. It's better to say that :it's a proper distance.
The ratio between the heights and length of left aerator ramps are:

First aerator: $\left(\frac{a}{b}\right) = \frac{0.98}{10} = 0.098,$
Second aerator: $\left(\frac{a}{b}\right) = \frac{1.06}{10} = 0.106$,
Third aerator: $\left(\frac{a}{b}\right) = \frac{1.04}{13.55} = 0.076$

After installing first aerator and measuring length of jump, it appears that maximum length of jump from first aerator is 25.6 m. there for maximum horizontal distance of jump from first aerator from the beginning of spillway is:195+25.6=220.6m.Second aerator is installed 255 meters away from beginning of spillway. It means horizontal distance of maximum length of jump from the first aerator in order to installation the location of second one is:255–220.6 = 34.4m.Therefore horizontal distance of first aerator and second one 255–195=60 meters that is an appropriate distance.
Maximum distance of jump from second aerator is 40.6 m. So horizontal distance of maximum distance of jump from second aerator at the beginning of spillway is 255+40.6 = 295.6m.third aerator is installed 355 meters away from beginning of spillway. It means horizontal distance of maximum horizontal length of jump from 2nd aerator to 3rd one is 355–295.6=59.4 meters. Thus horizontal distance between second and third aerator is 355–280= 125 meters. We can say it a proper distance too.

3-3 Shafaroud dam

Shafaroud dam is structured on six km away from southwest of Rezvanshahr and 65 km away from Rasht. Shafaroud dam, length of crest is 372m, crest width is six meters and the sank capacity is 98 million cubic meters of water.

3-3-1- Aerator system parts

Overflow threshold level of 214 meters, the gross surplus 61.8 meter and the establishment of three basic weirs is divided into four equal spans. Chute gradient of 0.75 to 1 (horizontal to vertical) are linked to flip bucket. Chute gradient of 0.75 to 1 (horizontal to vertical) are linked to flip bucket. In this system if we consider(a) the height of ramp and(b) as horizontal length of ramp this equation will be occurred: a/b= $\frac{0.242}{3.94}$ =0.061.Aerator ramp within 35 meters of the OEM spillway threshold and maximum horizontal length of the ramp jump Aerator 21.4 meters. The maximum distance of horizontal jump to the beginning of the weir is 56.4 m.

4. Results and Analysis

4-1 Cavitations calculation among spillway of Azad dam

Using velocity and static pressure measurement sat 12cross sections along the chute, by the Six rate, the water flow was 500per1800 (m3 / sec) by replacement in the (2nd) relationship. The corrosion rate was calculated.CorrosioncoefficientcurveinFigure1is presented.

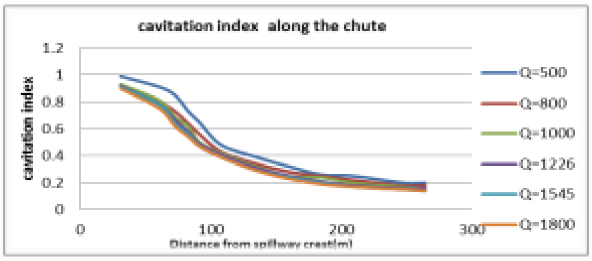


Fig (1) Cavitations coefficient variation among chute of spillway of Azad dam

According to Figure 1at a distance of 165 meters up stream of the first aerator overflow threshold is greater than the number of cavitations which the water flow is critical. Ata distance of160m from the threshold to the end chute markets over flow discharge water samples, the corrosion rate (δ<0.25) is below the critical line. Cavitations coefficient of variation before and after aeration weir at a distance of165 mfrom the threshold is obtained in Figure 2.

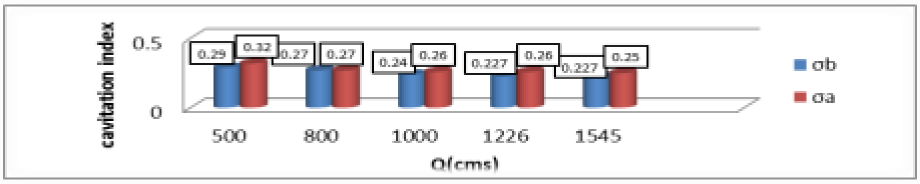


Fig (2): Coefficient of variation before and afteraerationcavitationsthresholdwithin165mof Azad dam spillway.

In this study, pre-aeration cavitations coefficient (before aeration) with [bσ] symbol and after aeration cavitations coefficient (after aeration) are shown with the symbol[aσ]. As it shows hereby considering the matter of cavitations coefficient is increased after aeration this coefficient in all discharges crosses critical cavitations coefficient threshold that is 0.25 and probability of cavitations is reduced when first aerator is installed in mentioned location. Cavitations coefficient of variation before and after aeration is shown in Figure 3 at a distance of 210m from the threshold.

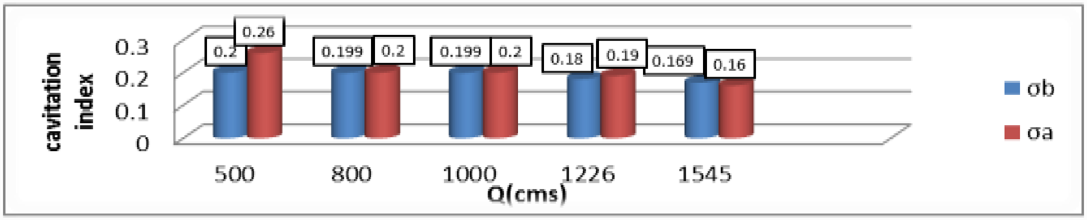


Fig (3): Coefficient of variation before and after aeration cavitations threshold at a distance of 210meter from Azad dam spillway.

According to the figure 3, discharge of 1545 cubic m/s (which is the biggest discharge in this study) Second aerator not only include acceptable performance but also with installing this aerator cavitations in this discharge there would be an increase a little. Finally we can find Minor differences between cavitations coefficient after and before aeration and the fact that cavitations coefficient didn't cross threshold of critical cavitations coefficient after aeration and notice that from 800 to 1545 cubic m/s discharges, cavitations coefficient is in range of 0.1 to 0.2. After aeration, it would be lead us to realize that second aerator system in spillway of Azad dam is not as much useful than it seems redesigning is inevitable.

4-2 Cavitations calculation among spillway of Gotvand dam

This is set from a distance of24/124meters from the overflow threshold and it issettostartcrosslauncher6 which cross areas is selected. Opening for a full four-valve-per-seven-state flow rate of 2,000 to15,000 cubic meters per second on each stage hydraulic parameters (water depth, velocity and static pressure) is measured. Corrosion coefficient curve in Figure 4 and5are presented.

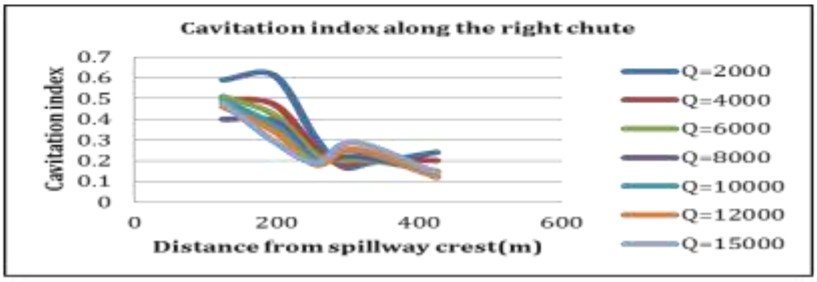


Fig (4) :cavitations coefficient curve at the end of chute (right channel) Gotvand dam

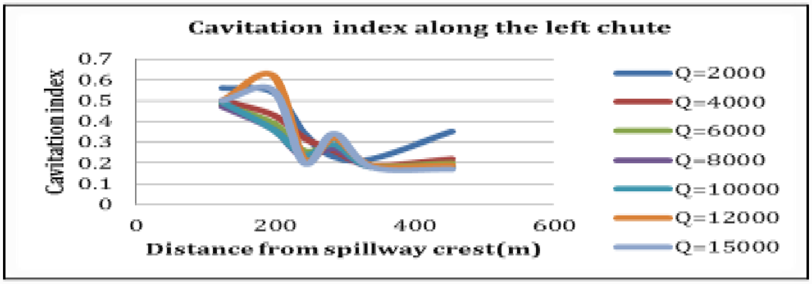


Fig (5): Cavitations coefficient curve at the bottom chute (left channel) Gotvand dam

According to figures 4 and 5 the distance from the overflow threshold Cavitations coefficient in almost all water flow decreases and increases the risk of cavitations phenomena. However, according to the distance from the overflow threshold of cavitations coefficient has fluctuated and this is probably related to the geometry of the shot. Cavitations coefficient variation before and after aeration 195meters away from beginning of the spillway is shown in figure 6

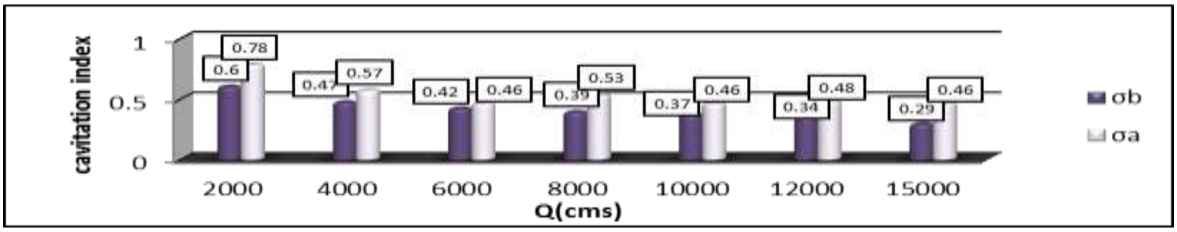


Fig (6): Corrosion coefficient of variation before and after the installation of the first aerator (right channel)

Fig (7) is cavitations coefficient variation chart before and after aeration 255 meters away from beginning of spillway.

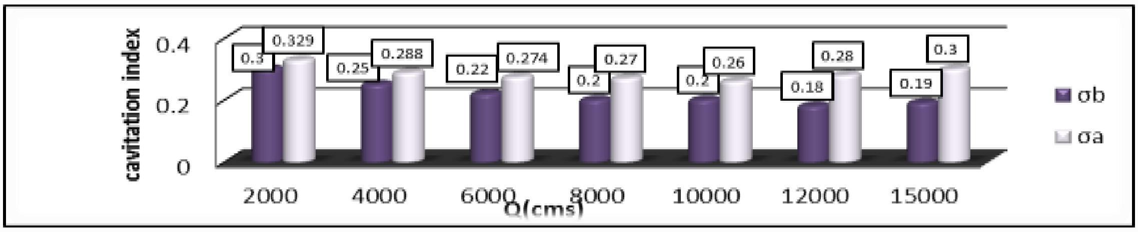


Fig (7): Cavitations coefficient of variation before and after the installation of the second aerator (right flow)

Fig (8) is cavitations coefficient variation chart before and after aeration 355 meters away from beginning of spillway.

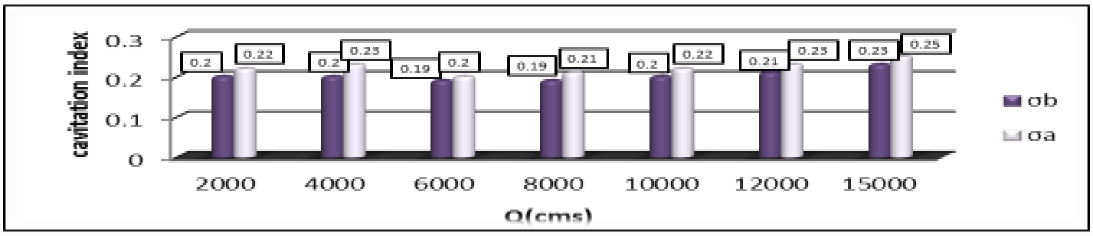


Fig (8): Cavitations coefficient of variation before and after the installation of the third aerator (right flow)

Fig (9) is cavitations coefficient variation chart before and after aeration 195 meters away from beginning of spillway in left flow.

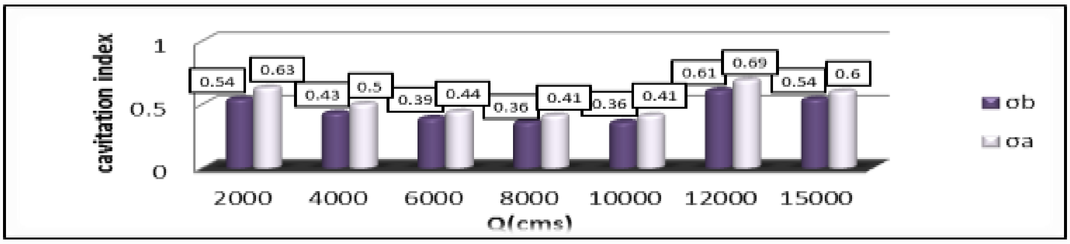
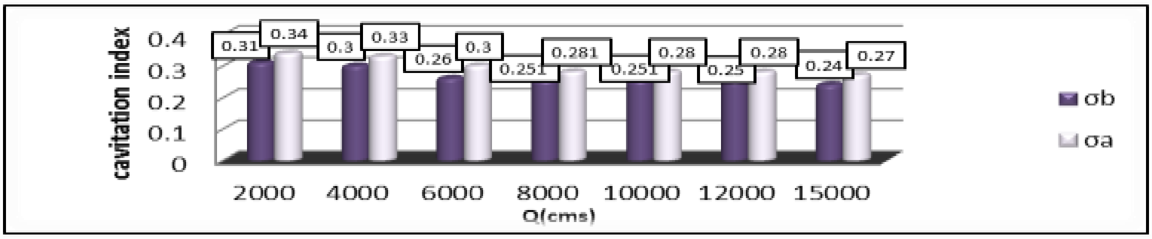


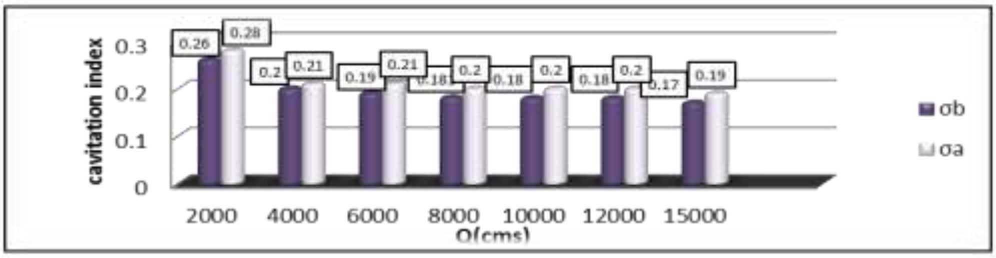
Fig (9): Cavitations coefficient of variation before and after the installation of the first aerator (left flow)

According to figures 6 and 9 the highest impact first aerator, is the 2000 (m3 / sec) discharge. The discharge flow rate in the range studied, has the lowest. Due to the cavitations coefficient increased after aeration, we can say that the first aerator system installed in each duct Dam is a good option. Figure (10) is cavitations coefficient variation chart before and after aeration 255 meters away from beginning of spillway in left flow.



Fig(10) Cavitations coefficient of variation before and after the installation of the second aerator (left flow)

According to figures 7 and 10, and given that the coefficient of cavitation. After aeration, the flow rates were increased and exceeded the critical 0.25 is passing, it can be said that the system aerator two installed in each duct dam is a good Option. Figure (11) is cavitations coefficient variation chart before and after aeration 380 meters away from beginning of spillway.



Fig(11) Cavitations coefficient of variation before and after the installation of the third aerator (left flow)

According to figures 8 and 11, which given that the coefficient of cavitation after aeration has a slight increasing, and except in the discharge of 2,000 cubic meters per second Crossing the border is not critical cavitations coefficient، We can say that the third aerator system installed on both channel dam, is not suitable.

4-3 Cavitation calculation among spillway of Shafaroud dam

for Six discharge, hydraulic was measured. Using the results of the mean velocity and static pressure on the six sections and replacing it in equation (2) corrosion rate was calculated.The results in Figure (12) are given.

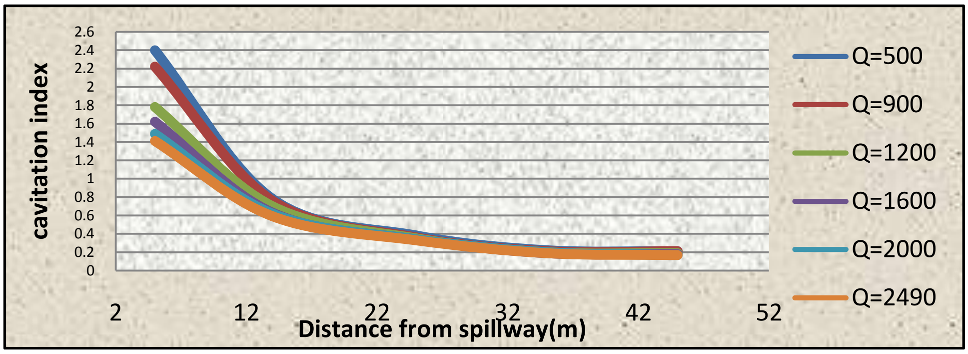


Fig (12) Cavitation coefficient variation among chute of spillway of shafarood dam

According to figure (12), the lowest corrosion rate is 0.169, which is related to the discharge end of 2490 cubic meters per second are Chute. Distance of 35 meters from the spillway threshold, the corrosion rate of six per discharge is smaller than the critical value. Seems to use the stairs or ramp Aerator at 35m distance (horizontal distance relative to the weir crest), can reduce the damaging effects of this Phenomenon.Conditions of cavitations coefficient before and after the installation of aeration systems, aerator and measured results in Figure (13) below is defined as discharge increases.

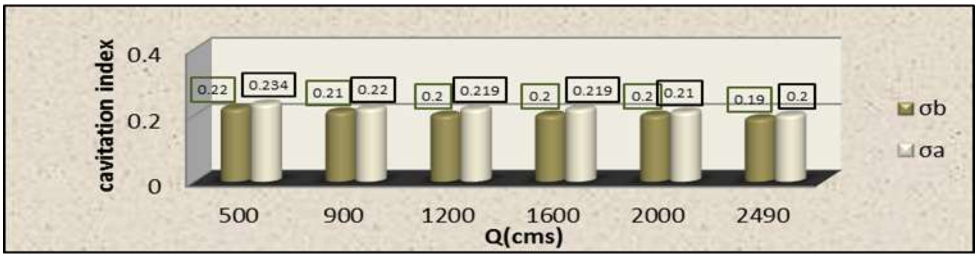


Fig (13) Cavitation coefficient of variation before and after the installation of theaerator

Is defined as discharge increases, the cavitation coefficient of discharge (before and after aeration) reduced risk of cavitation increases with increasing discharge. Due to the cavitation coefficient increased after aeration was very little, and In none of the studied flow rate of aeration cavitation threshold of 0.25 no more, Can be said The system can be installed in the dam Shafaroud aerator aeration is not an option and the risk of cavitation phenomenon still remains.

4-4 Aerator systems installed compares the performance of the dam spillway

After installing aerator system in selected intervals (especially in location of aerator) we calculated cavitation number and realized that if the system was practical or not. In the end we compared efficiency of aerators in spillways of mentioned dams and studied affection of possible parameters on efficiency of aerator ramps.Finally, the performance comparison between the spillway aerator azad and gotvand dams that have more than one aeration systems can lead to acceptable results.

4-5 investigating performance of first aerator of spillway of Azad dam and first aerator of right flow of Gotvand dam

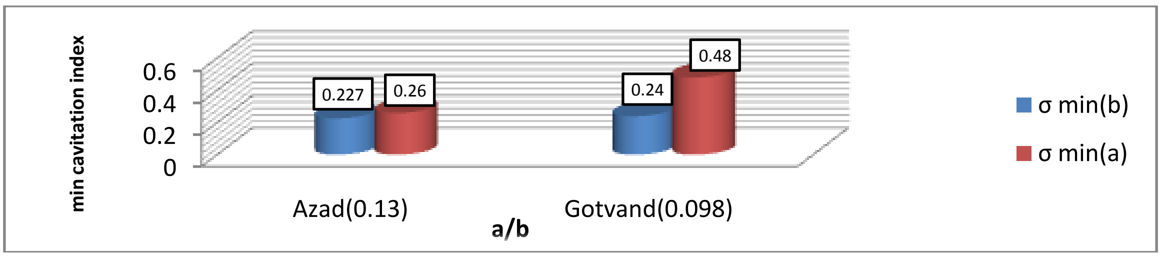


Fig (14) minimum cavitation coefficient changes curve considering a/b (first aerators and right flow of Gotvand dam)

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Dam	a	b	h	a/b	L j	Chute slope
Gotvand	0.98	10	74	0.098	13.3	3.5
Azad	0.5	3.76	77.5	0.13	24	36.4

Table (1) investigation on effective factors on performance of aerator ramp (first aerator of Azad dam and first aerator of right flow of Gotvand)

a: height of ramp in meters. b: horizontal length of ramp in meters. h: height difference of beginning and ending part of spillway.a/b: ramp's height to it's length. L_j: maximum horizontal jump from ramp in meters. Chute slope: chute slop in degrees.
According to table above performance of aerators increases in situations mentioned below:

1. More height and horizontal length of aerator ramp.2-Less difference between beginning and the end of spillway.3-Less a/b ratio.4-Maximum throwing jet must be less than aerator of spillway.5-Less chute slope.

4-6- a compare of performance of second aerator of Azad dam's spillway and second aerator of right flow of Gotvand spillway.

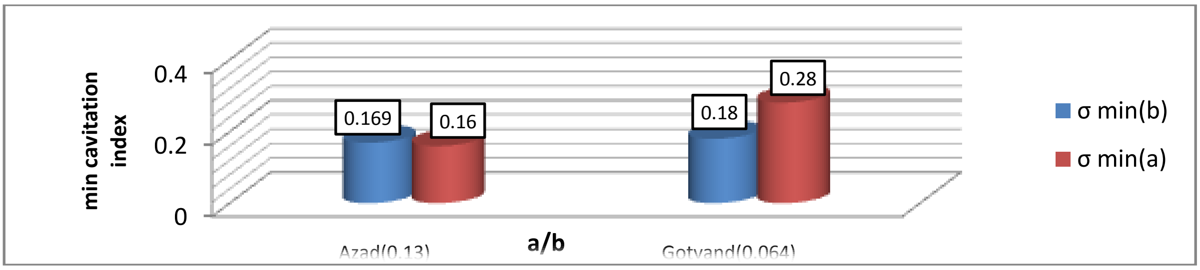

Fig (15) minimum cavitation coefficient difference, having a/b (second aerators and right flow of Gotvand dam)

Dam	a	b	h	a/b	L j	Chute slope
Gotvand	0.64	10	74	0.064	25	3.5
dAza	0.5	3.76	77.5	0.13	57	36.4

Table (2) discovering effective factors on performance of aerator ramp (second aerator of Azad dam and second aerator of right flow of Gotvand dam)

According to table above we can say performance of aerators rises in below conditions:

1. More height and horizontal length of ramp.2-Less difference between height of start and end of spillway.3-Less a/b ratio.4-Maximum throw length must be less than aerator of spillway.5-Less chute slope

4-7 review of performance of first aerator of Azad dam's spillway and first aerator of Gotvand dam's right flow.

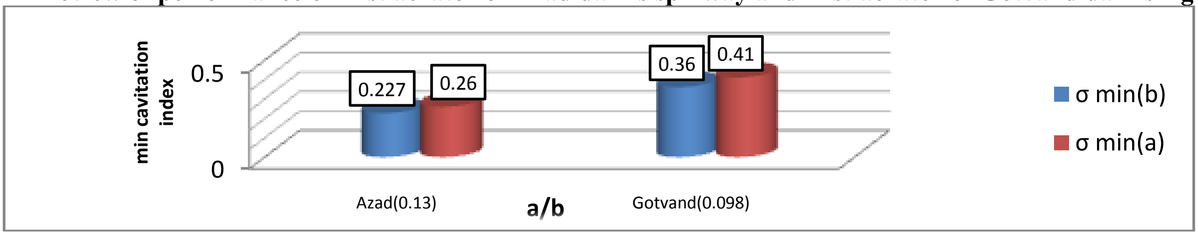

Fig (16) minimum cavitation coefficient difference considering a/b (first aerators and left flow of Gotvand dam)

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Dam	a	b	h	a/b	L j	Chute slope
Gotvand	0.98	10	58	0.098	12.3	3.5
Azad	0.5	3.76	77.5	0.13	24	36.4

Table (3) discovering effective factors on performance of aerator ramp (first aerator of Azad dam and first aerator of left flow of Gotvand dam)

According to above table we can say performance of aerators rises in conditions below:

1. dams with more than one aerator, more ramp height and length makes aerator more efficient.2-Less difference between height of start and end of spillway.3-Less a/b ratio.4-Maximum throw length must be less than aerator of spillway.5-Less chute slope.

4-8 review of performance of second aerator of Azad dam's spillway and second aerator of Gotvand dam's left flow.

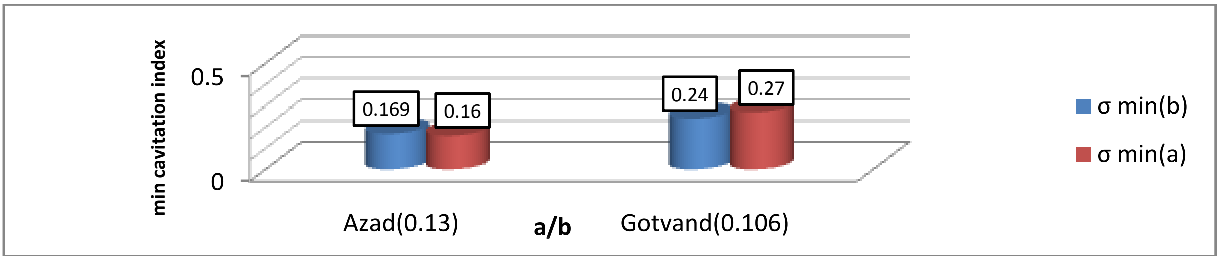

Fig (17) minimum cavitations coefficient difference considering a/b (second aerators and left flow of Gotvand dam)

Dam	a	b	h	a/b	L j	Chute slope
Gotvand	1/06	10	58	0.106	29	3.5
Azad	0/5	3.76	77.5	0.13	57	36.4

Table (4) discovering effective factors on performance of aerator ramp (second aerator of Azad dam and second aerator of left flow of Gotvand dam

According to above table we can say performance of aerators rises in below conditions:

1. In dams with more than one aerator, more ramp height and length makes aerator more efficient.2-Less difference between height of start and end of spillway.3-Less a/b ratio.4-Maximum throw length must be less than aerator of spillway.5-Less chute slope.

5 Conclusions

1-Azad dam has two aerators in distance of 165 and 210m away from start of spillway. Considering that cavitations coefficient rises after aeration in all discharges and crossed the critical threshold, which is 0.25; we can point at decrease of probability of cavitations with installation of first aerator in mentioned distance. In second aerator's location cavitations coefficient not only hasn't increased that much but also in 1545 cubic m/s discharge, cavitations coefficient decreased and probability of cavitations rises with installing second aerator. Totally we can say considering that in second aerator only in discharge of 500 cubic m/s, cavitations coefficient after aeration crossed critical threshold, so second aerator only in this discharge is efficient for avoiding cavitation.2-Gotvand dam has two flows and each of them has 3 aerators. In right flow aerators are installed 195, 255 and 355 meters away from start of spillway. First aerator is a good choice for avoiding cavitations. In second aerator: As it is obvious cavitations coefficient after aeration in all discharges crossed the critical threshold we can say that second aerator was a good option. In third aerator: The point is that none of discharges cavitations coefficient didn't cross the critical threshold. So third aerator was not a good option. In left flow aerator distances from start of spillway are 195, 255 and 380 m. in first aerator: Considering increase of cavitations coefficient after aeration we can say that first aerator of right flow of Gotland dam was a good option to avoid cavitations. In second aerator: the numbers represent that cavitations coefficient in all discharges made a big distance to critical threshold which is 0.25. So it was a good option to install second aerator in left flow of Gotland dam. In third aerator: Cavitation coefficient after aeration has a minor exceptional increase in 2000 discharge which is lowest discharge in study, with this aerator cavitation coefficient didn't cross the critical threshold and therefore third aerator of left flow of Gotvand was not a good option for aeration.3-In Shafaroud dam with a spillway aeration is at a distance of 35m from the threshold, considering the cavitation coefficient increased after aeration was very little, In none of the studied flow rate of aeration cavitation threshold of 0/25 no more, It can be said that a single system installed in the Shafaroud dam aerator, it is not a good option.4- We can do a comparison between Azad and Gotvand dams. Because these two dams have more than one aerator among spillway each. In a survey on different situations (first aerator of spillway of Azad dam and first aerator of right flow of Gotvand dam, first aerator of spillway of Azad dam and first aerator of left flow of Gotvand dam, second aerator of spillway of Azad dam and second aerator of right flow of Gotvand dam, second aerator of spillway of Azad dam and second aerator of left flow of Gotvand dam) we can say with less a/b ratio and chute slope and less maximum horizontal jump length from aerator ramp and less height difference between start and end part of spillway and more height and horizontal length of aerator ramp we have more efficiency and performance over the aerator.

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