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Examining the effect of cavitation on crest spillway using Ansys-fluent software

Ali Eskanadari Sabzi [1, *], Ali Afrous [2]

[1]Department of Hydraulic structures, Dezful Branch, Islamic Azad University, Dezful, Iran
[2]Department of Engineering, Andimeshk Branch, Islamic Azad University, Andimeshk, Iran

Abstract: The numerical model being investigated is the two-dimensional model of crest spillway without gates whose geometrical characteristics are presented by USACE. In this research, VOF method was used to determine the water level. Two-equation model k- ε (RNG) was used as the turbulence model and SIMPLE algorithm was used to couple velocity and pressure equations. The results obtained through this study are different from the experimental results of non-hydrostatic pressure distribution on gated crest surface published by ASACE for various H/Hd. Studies indicate good conformity of numerical results with the published laboratory results. It can be stated in this research that if the increase of velocity and consequently the negative pressure developed in the spillway with the basic slope tested by USACE do not lead to the occurrence of cavitation, the other spillways examined in this research will not witness the development of cavitation, either. Otherwise, the cavitation development can be prevented only by softening the spillway constant slope.

Key words: Ansys Fluent software; Crest spillway; Examining cavitation

1. Introduction

Chutes and spillways are important hydraulic structures that play a key role in the stability of dams. The most important factor that might endanger the stability of spillways is vacuum creating phenomenon. Among the factors contributing to the occurrence of cavitation are pressure, flow velocity, air flow rate, duration of operation, and strength of materials can be referred to. When the vacuum creating phenomenon occurs, small bubbles or cavities resulting from the vacuum phenomenon reach the downstream area which has higher pressure and due to the increase of pressure the above bubbles are destroyed suddenly. If the bubbles are destroyed near the concrete surface they will damage the spillway. Therefore, pressure is one of the most important factors affecting the spillway in vacuum phenomenon.

Investigating the effect of flow on the crest of spillway for the flow discharges greater than the designed flow is highly significant in designing the crest of spillway so that if the imposed pressure on the crest of spillways is less than the atmospheric pressure, the negative pressure on the spillway that occurs for the flow discharges greater than the designed flow causes cavitation. This phenomenon has caused irreparable damage to many hydraulic structures. Among the hydraulic structures that are facing this phenomenon Shahid Abbaspoor Dam can be referred to. Due to flow discharges greater than the designed flow, the dam spillway has been faced with some problems. Another example is Garmasar diversion dam whose spillway crest has been affected by corrosion and cavitation.

Experience has shown that the high speed of water on the concrete surface of spillways can lead to damage resulting from cavitation. Projections and roughness of concrete surface that appear during or after the construction of concrete cause the diversion of flow lines and also low pressure areas in some places so that if the low pressure does not reach the limit of vapor pressure, cavitation will appear. It should be mentioned that although the use of high strength concrete prevents the damage resulting from high velocity, in case of cavitation even this condition cannot prevent its damage.

The possibility of cavitation development due to the effect of flow on non-flat surfaces was investigated by Johnson in 1963 and by Ball in 1975 and 1976. In 1979, some research was carried out by Wang and Chou in this regard.

Arndt (1976) has shown that cavitation can develop on surfaces with uniform roughness. In this case, initial cavitation number and cavitation index of such surfaces will be as $K_1 = 4f$ (f = Darcy – Weisbach resistance coefficient).

2. Method

The model studied in the research is the two-dimensional model of crest spillway without gates whose geometric features are presented by USACE in HDC 111-16 diagram. The present reports include the amounts of cavitation index, pressure distribution, and velocity on the surface of crest spillway. Therefore, after constructing two-dimensional geometry of spillway model, the model

* Corresponding Author.

was meshed and the kinds of boundary conditions were determined. VOF method was used to determine the water level, two-equation model k- ε (RNG) was used as the turbulence model and SIMPLE algorithm was used to couple velocity and pressure equations. By implementing the numerical model in Ansys-Fluent environment, the obtained results were compared with the results reported by USACE. The studies indicate that the numerical results are well consistent with experimental results.

3. Applied experimental model

For modeling, the standard gated crest spillway of USACE (USACE, 1952) has been used whose discharge coefficient, pressure distribution, and other hydraulic parameters are determined. The spillway upstream is made up of a flat vertical surface and is connected to the spillway crest with a curve which is made of the sectors of three circles with the radii of 0.5Hd, 0.2Hd, and 0.04Hd. The spillway surface after the crest involves crest part and stable slope and the crest section follows the equation (1-4).

Equation (1-1): $X^n = kH_d^{n-1}y$

Where k=2, Hd = 15.24 m (50 ft) and n = 1.85.
The slop of the straight part is 45° (1/1:1).

The details of the level of gated crest spillway, under the study, are shown in Fig. 1. Since the modeling is two-dimensional the unit thickness is intended for Z direction. In order to insure that the results of the experiment are published with the least amount of error during the experiments, some of the experiments have been repeated. The results of the experiments published by USACE for crest spillway, involve the pressure distribution on the surface of crest spillway and at different levels of water in the crest upstream.

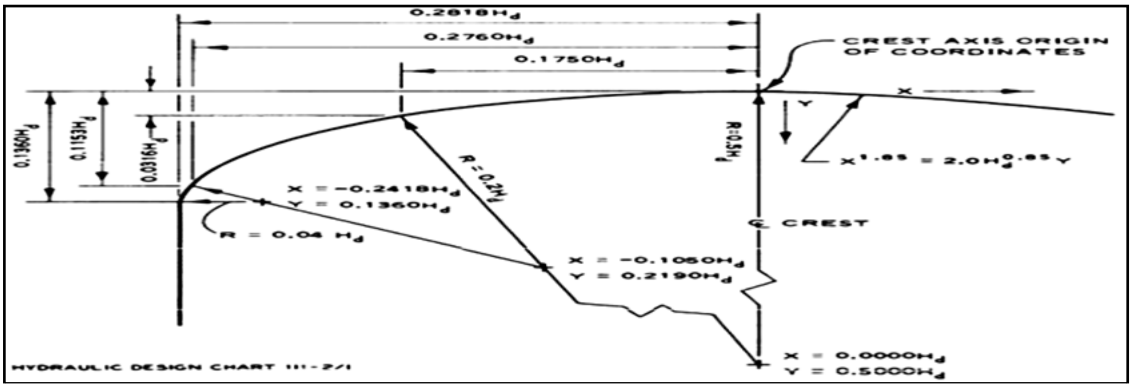


Fig. 1: Details of standard crest spillway surface

The flow discharge over the crest spillway is calculated through Equation (1-2):

Equation (1-2): $Q = C L H_e^{(3/2)}$

Where C is the discharge coefficient, L is the width of crest spillway which is considered as the unit in this research, H_e is the height of water from crest spillway level to the water surface according to Fig. 2. I order to calculate discharge coefficient, HDC 111-3 presented by USACE has been used (USACE, 1952).

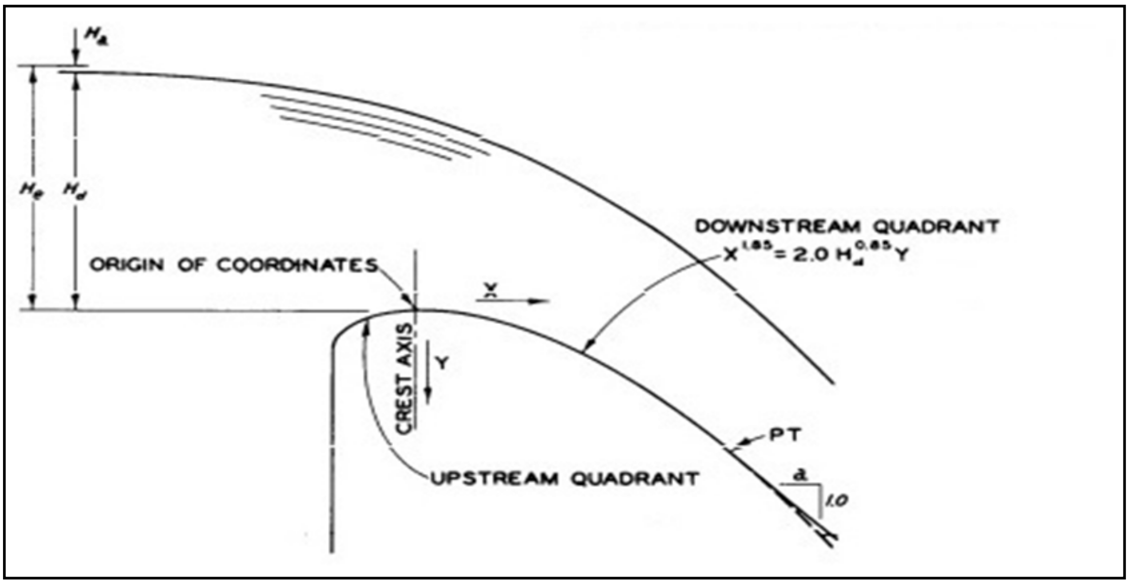


Fig. 2: General Schema of crest spillway without gates (USACE, 1952)

Cavitation index is the most important tool used for the estimation of cavitation. Cavitation index is obtained through the following equation (USACE, 1952).

Equation (1-2)

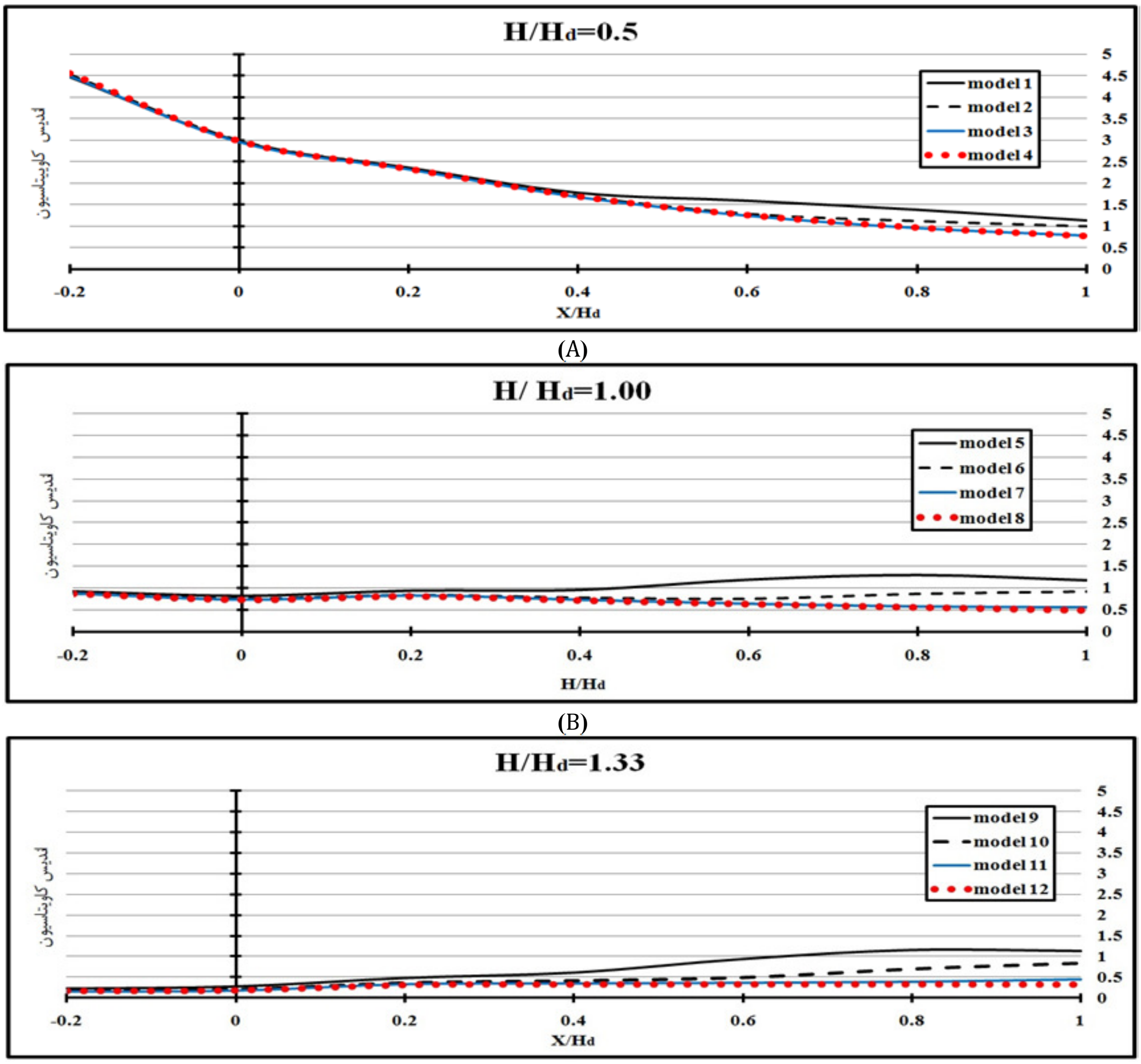
$$\sigma = \frac{(p - p_v)}{\frac{\rho V^2}{2}}$$

Where, σ is cavitation index, V is flow velocity, P and P_v are absolute pressure of flow and vapor flow. The fluid vapor pressure at 20̊ C is 0.023 atmospheres.

According to documented reports, the fluid is exposed to the risk of cavitation when the cavitation index is not less than a critical value. On the levels of outlet channels and spillways this value ranges from 0.2 to 0.25 (USACE, 1952). In this research the cavitation index is considered to be o.25 for sure.

Fig. 3 shows the values of cavitation index for places with certain longitudinal coordinated from the crest of spillway (center of numerical model coordinates) at different hydraulic heads. As displayed in diagrams, cavitation index in hydraulic loads of 0.5 and 1.00 is always more than the critical value. Therefore, the cavitation is unlikely to occur on the surface of crest spillway in the crest section. However, due to the increase of velocity and decrease of pressure the cavitation is likely to occur after this area which requires the detailed investigation of cavitation on the whole surface of spillway structure.

Cavitation is likely to develop at the spillway crest upstream for the hydraulic load of 1.33 according to the value of cavitation index in Fig. 3, (C). This area is prone to cavitation and hence some measures should be considered to be taken to prevent the intensification of cavitation in this area. According to the diagrams in Fig. 3 it is observed that cavitation index has increased as the slope at constant slope sector has moderated. This means that the increase of slope at constant slope sector increases the probability of cavitation development on the surface of spillway.



(C)

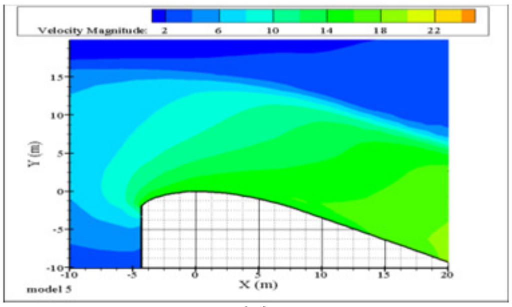
Fig. 3: Cavitation index in the surface of crest spillway with gates for the hydraulic load of (A): 0.5 H_d, (B): 1.00 H_d, (C): 1.33 H_d

Table 1: The features of the studied models

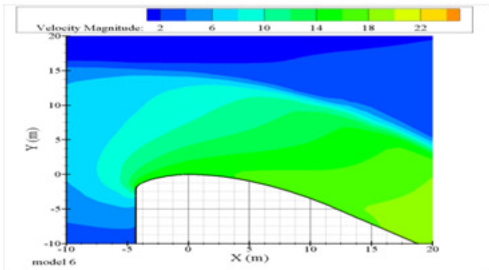
Model	Constant slope	C	H/Hd	Q (kg/s)
Model 1	30^0	3.612	0.5	41874.5
Model 2	37^0	3.612	0.5	41874.5
Model 3	45^0	3.612	0.5	41874.5
Model 4	60^0	3.612	0.5	41874.5
Model 5	30^0	3.922	1.00	127306
Model 6	37^0	3.922	1.00	127306
Model 7	45^0	3.922	1.00	127306
Model 8	60^0	3.922	1.00	127306
Model 9	30^0	4.077	1.33	205024
Model 10	37^0	4.077	1.33	205024
Model 11	45^0	4.077	1.33	205024
Model 12	60^0	4.077	1.33	205024

With regard to the rate of velocity at different points of spillway (according to the following diagrams), despite the fact that velocity in the crest upstream of crest spillway does not change as the slope of constant slop sector changes and nearly remains the same in all states, the velocity in the crest downstream is entirely influenced by the change of constant slope so that as the slopes get steeper the rate of velocity on the surface of spillway will increase. This is one important factor leading to pressure drop. More attention to velocity distribution obtained for the studied models shows that the increase of velocity in steeper slopes (45° and 60°) is almost the same, so the pressure difference on the surface of spillway in these two states is not very different from that of crest sector.

Figs. 4 clearly show that the velocity of fluid overflow on the spillway increases as the constant slope gets steeper. Moreover, the increasing trend of velocity, as the hydraulic load of reservoir increases, is more for the spillways with steeper constant slope than the spillways with milder constant slope. This matter becomes more apparent when the rate of pressure drop is noticed in four states of constant slope as the hydraulic load increases because the rate of pressure drop for mild slope is less than that of steep slope.



(A)



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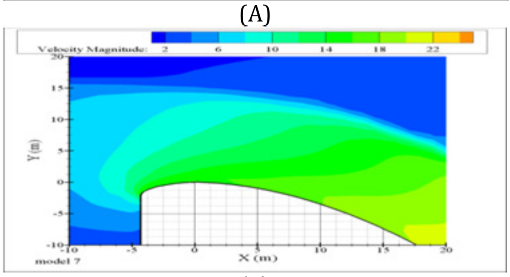

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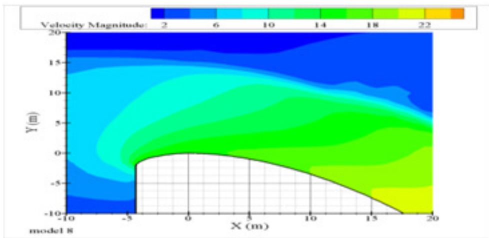
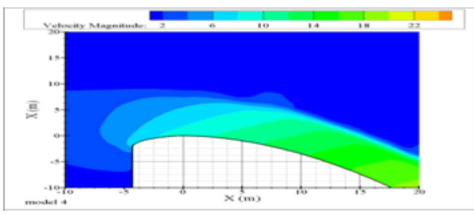


(D)

Fig. 4, A: Velocity distribution on crest spillway with the hydraulic load of 1.00 for the spillway with the constant slope of: (A) 30°, (B) 37°, (C) 45°, and (D) 60°.



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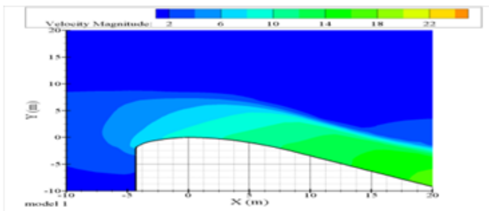

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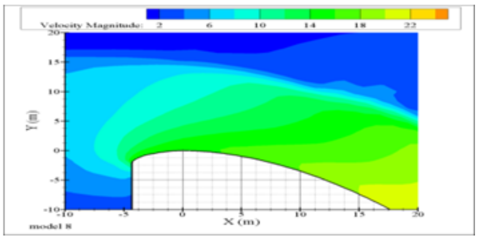

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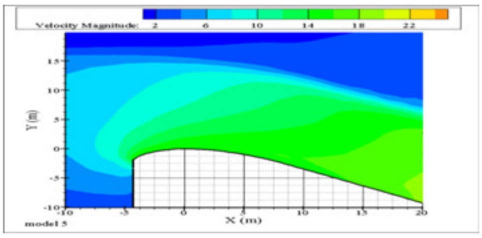

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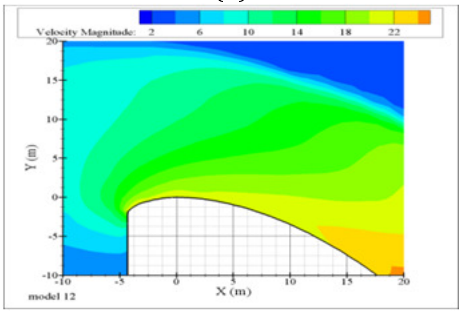

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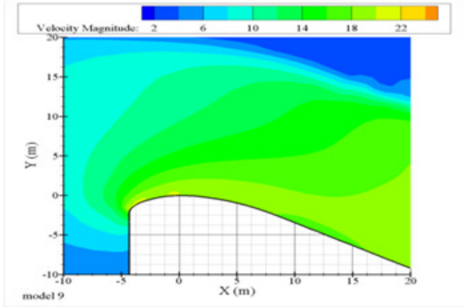
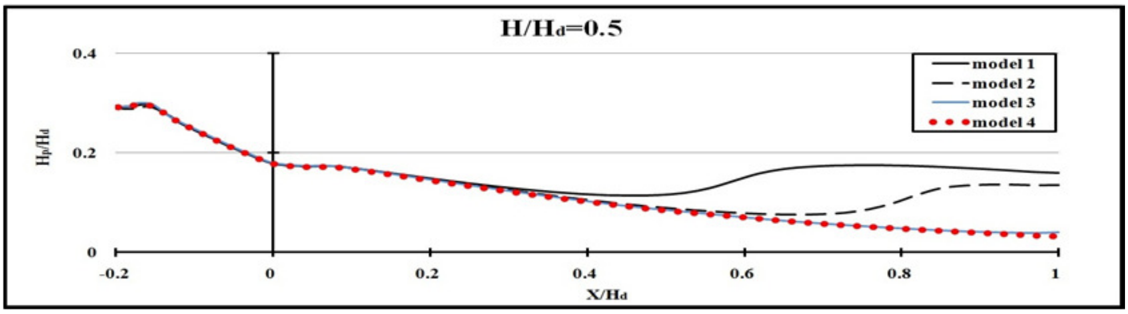
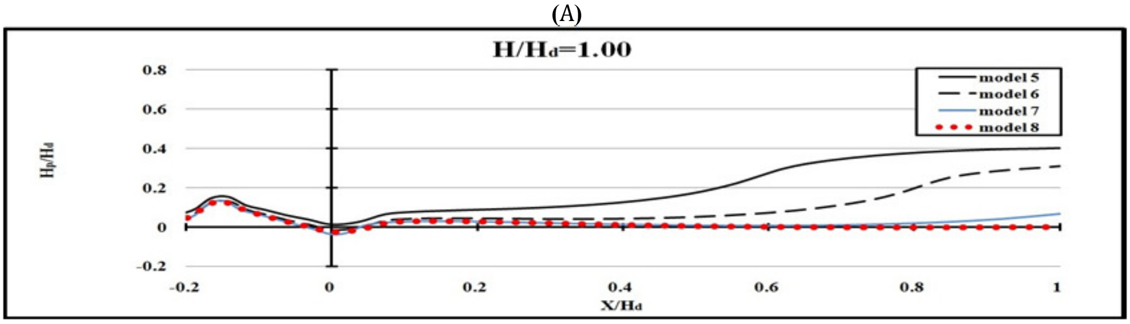


(B)

Fig. 4, B: Velocity distribution on crest spillway with different hydraulic loads for spillway with the constant slope of (A) 60°, (B) 30°



(A)



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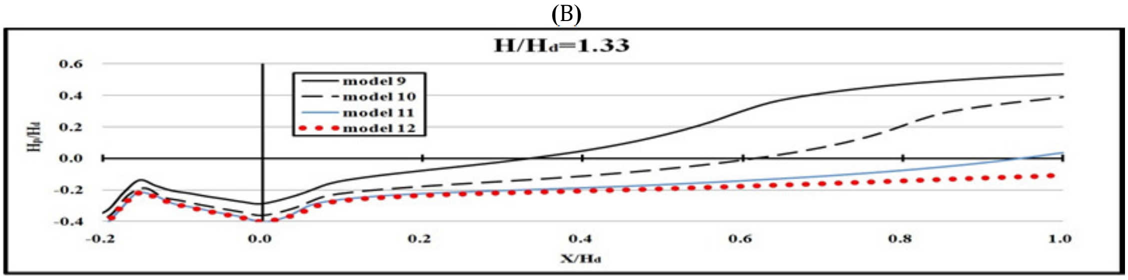

(C)

Fig. 5: The results of pressure distribution on the surface of crest spillway for the mentioned models in the hydraulic loads (A) Hd0.5, (B) Hd 1.00, (C) Hd 1.33

4. Conclusion

According to the obtained diagrams the important point is that as the rate of constant slope changes, the magnitude of maximum negative pressure doesn't change or it decreases as the hydraulic load of reservoir decreases. This is an important point in the development of cavitation because it can be stated that, due to this problem, if the negative pressure developed in the spillway with the basic slope tested by USACE does not lead to the occurrence of cavitation, the other spillways examined in this research will not witness the development of cavitation, either. Otherwise, the cavitation development can be prevented only by softening the spillway constant slope. Moreover, as the constant slope gets milder, the cavitation index on the surface of spillway increases and consequently the possibility of cavitation development on the crest surface of spillway decreases

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