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Research Article

Investigating the impact of the vortex breaker on the hydraulics of the flow (empirical hydraulic coefficient) passing over the morning glory spillway

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Abstract

In recent decades, many dams have been built. Due to the high need for water and the increasing soil erosion in different areas, the need and sensation to build a dam is quite obvious. In 1900, the number of large dams did not exceed 50. However, between 1950 and 1986, the number of large dams (more than 15 meters high) was more than 39,000. Since the 70s, the construction of dams has been developing more and more. This expansion has been more visible in the Asian, Central and South American regions. According to the construction purpose, each dam structure must be able to pass the volume of excess water caused by the flood, and for this purpose, various structures such as spillways are used. The spillways are different according to the type of exploitation and the type of project. In other words, there are different types of leaks. Which are one of these types of shaft spillway. The spillway of a morning glory consists of a circular crest that directs the flow to an inclined or vertical axis. The mentioned axis is connected to a conduct way with a low gradient. In this research, in order to investigate the performance of both vortex breakers on the hydraulic spillway of morning glory, several tests have been conducted with various types of vortex breakers. The results show that the best vorticity channel with a low height and length is an arrangement of 6, which increases the flow rate by 23%. It should be noted that increasing the thickness of the vortex breaker by more than 7% of the spillway radius does not have much effect on the increase of the hydraulic coefficient.

Keywords:

Morning Glory Spillway, Vortex Breaker, Arrangement, Hydraulic Behavior

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1- Introduction

In general, the spillway is installed to drain excess water or floods when the volume of the reservoir is not able to store water. In diversion dams, the spillway is used to bypass or divert excess flow from the system capacity. The destruction of many dams occurs due to improper design or insufficient capacity of the spillway. Morning glory spillway is a separate spillway that can replace the side spillway. This spillway consists of a circular opening inside the sea, a vertical circular transition and a tunnel under horizontal (or almost horizontal) pressure, which finally transfers water from the lake to the downstream part of the dam. In other words, the spillway of a lotus consists of a circular crown that directs the flow to an inclined or vertical axis (1). Carrying out solutions to increase the flow rate and discharge coefficient of Morning glory spillways is of particular importance, and the optimal use of vortex breaker blades can also have a greater effect on increasing the flow rate and discharge coefficient of Morning glory spillways.

Image (1) the view of old stepped morning glory spillway in operation

Using a vortex breaker on lotus spill ways, which has been done in a very limited way and only on simple lotus spill ways, can be an effective step in using this type of spill ways. Researches have been done in this field. Khatsuria [1], this researcher conducted studies including pressure, absorption ratio and discharge coefficient on smooth spillways, the results of this researcher were in agreement with the results of the American Civil Service regarding smooth lotus spillways [2].

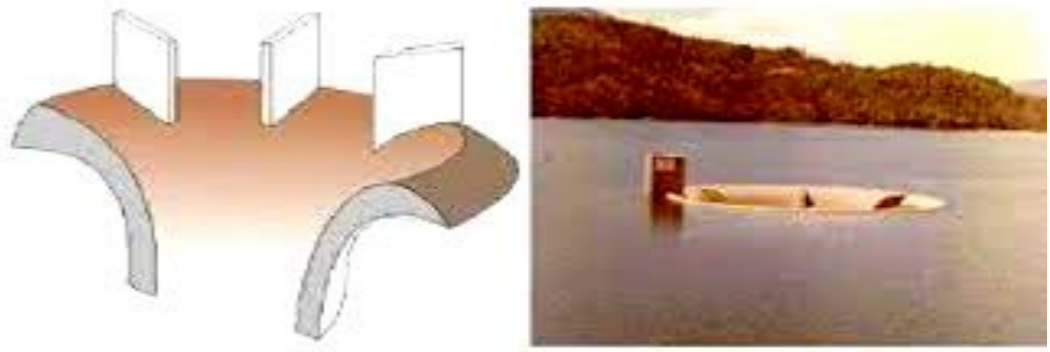

Image (1) the view of vortex breaker morning glory spillway in operation

Bagheri (2001) by building a laboratory model, including an approach channel and a pond connected to it, investigated the effect of the tangential component of the approach flow speed and the height of the Morning glory spillway on its discharge coefficient with 216 tests [3].

2- Literature review

The glory spillway is commonly used to deplete the flow along the flood. This hydraulic structure is capable to switch the free surface flow to fluid flow through the pipeline which is caused that the glory spillway thread by high velocity flow and flow separation. These cases can generate the cavitation bubble through the glory spillway. The cavitation phenomena are 37 commonly happened through the flow with high velocity and minus pressure. The glory 38 spillways included as three main parts as the vertical shaft, bend pipe and horizontal shaft. Some 39 studies were focused on the depletion of the water through the vertical structure such as drop 40 structure which consists of dive flow and vortex drop structures due to free and semi-submerged 41 flow [1,2,3]. Whirling flow is considered as a basic problem in designing of the hydraulic 42 structures with vertical shaft because it can mix the air and water and due to lack of the air above 43 the water surface, the minus static pressure can be generated by circulated currents [4].

Image (3) the view of hudge dimension of morning glory spillway

There are some researches in the literature which are argued the vortex drop structures and its 45 impacts on the minus pressure at bottom of the hydraulic structure [5,6,7,8]. The results of these 46 researches expound that one of important matter during design process for hydraulic structure is 47 predicting some countermeasures to control and avoid minus static pressure. Also, through the 48 hydraulic structure with vertical and horizontal shafts, the high values of the streamwise velocity 49 can increase the threat of the cavitation danger risk, [9,10]. 50 The morning glory shaft is a type of spiral inlet which including of three main components: an 51 inlet morning glory spillway, a vertical shaft, and an outlet tunnel [11]. Switching the angel of 52 the mounted spoilers at the intake of the morning glory spillway can increase the values of the 53 coefficient discharge. Meanwhile, these spoilers can control the rotation of the vortexed-currents 54 and as a result the flow separation at the crest of the morning glory spillways tends to negligible 55 status [12,13]. Glory spillways are one of the major hydraulic structures in dams, which are 56 appropriately designed to pass the flow properly and effectively. Therefore, for correct and 57 optimal designing, various conditions should be examined to avoid negative pressures at the 58 spillway crest and other parts of the glory spillways which may cause instability in the spillway 59 structure and damage to the concrete surface of the spillway due to cavitation phenomena [14]. 60 Considerable research has been conducted to determine the effect of the shape of the crest of the 61 morning glory on the aeration. Esmailzadeh and Mirzavand indicated that adjusting and 62 mounting the deflector at the crest position of the morning glory spillways can increase the rate This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4329747 Preprint not peer reviewed 3 63 of the aeration. It was deduced that raising the aeration rate at the crest position of the morning 64 glory spillways can reduce the risk of the cavitation because of removing the minus static 65 pressure induced through the vertical shaft. [15].

Addition of the shape of the morning glory 66 spillway, the upstream slope of the intake is important parameter related to shape to avoid from 67 the minus pressure at crest position and downstream position of the intake such as vertical shaft 68 and bend pipe [16]. Most of available information is include a wide range of data that has been 69 obtained from the results of physical models done by USACE and USBR [17]. Regarding 70 morning glory spillways, the USBR has done valuable research on the shape of the crest and the 71 passing discharge that their results are available in the form of graphs and tables in the Institute's 72 publications. According to available data from USACE and USBR, computational fluid 73 dynamics (CFD) program, Flow-3D, for different levels of flow for modeling of the morning 74 glory spillway were introduced as an acceptable and reliable application to investigate the 75 parameters of the flow due to different submergence ratio To determine to hydraulic characteristic of flow in morning glory shaft spillways, many 77 researchers have tried to solve these issues or problems by using some methods such as 78 prototype measurements, experimental and computational methods [18 ,8,19,20,21,22,23]. The 79 numerical model was first used by Cassidy [24] to determine the water surface level and the 80 static pressure on the glory spillway crest based on a two-dimensional potential flow.

Their result 81 illustrated the numerical models are suitable to simulate the flow over the morning glory 82 spillways. The results also indicated that the minimum pressure for a given head depends on the 83 boundary conditions. Ikegawa and Washizu [25] and Betts [26] used the finite element method 84 linearly to solve the equations governing the flow field. The results obtained were compared by 85 Cassidy results. They found the speed of convergence increased in the numerical analysis. 86 Savage and Johnson [27] studied the morning glory spillways with ogee crest without the runoff 87 impact using Randomized Group Model (RNG). Their comparison shows the discharge and 88 pressure distribution over the spillway can be accurately predicted by employing numerical 89 models. Olsen and Kjellesvig [28] solved Reynolds averaged Navier-Stokes equations and also 90 analyzed the passing flow over the glory spillway using standard k - ε equations by considering 91 the two and three-dimensional model. Their results indicated that the numerical model can 92 achieve an appropriate solution for calculating the viscosity, kinetic and pressure forces. Fiedler 93 [29] presented the new designs of the Hoover Dam Spillways. He focused on the effective 94 parameters of the morning glory spillway demolition such as spillway capacity/dam overtopping 95 issues; spillway conveyance capacity; gate performance in non-flood situations; and performance 96 of spillway linings under high velocity flow to prevent cavitation. Results of this studies.

predicted the values of the discharge coefficient for the stepped100 morning glory spillways namely circular and quadrate experimentally. Also, the values of the 101 discharge coefficient predicted equally by using ANN and MNLR approaches. Results showed 102 that the values of the discharge coefficient of stepped morning glory spillway reduced by 103 increasing the ration of the H/R (where H is the active water head above the crest and R is the 104 radius of the morning glory spillway). Liu et al. [31] simulated flow in a newly developed vortex 105 drops shaft spillway using experimental and numerical methods. In this study, hydraulic 106 characteristics such as the flow pattern, air core distribution, annular hydraulic jump position, 107 pressure profiles, and water profiles of the outlet tunnel are obtained and agree well with the 108 measured experimental data. Results displayed that the flow around the inlet is apportioned into 109 a free-flow swirling region near the piers and submerged-flow region at the piers. Also, analytic 110 calculations for the resultant velocity and water course thickness of the shaft sections were 111 correlated well with the results of a numerical simulation. Cavitation is defined as the formation 112 of a bubble or void within a liquid. If the void is filled primarily with water vapor, the process is 113 further classified as vaporous cavitation [32]. 114 Aghamajidi et al. [33] studied hydraulic behavior of smooth surface on the performance of the 115 morning glory spillway and compared its results with an experimental type stepped-spillway 116 with and without vortex breakers. To study the risk of the cavitation, the Froude number, index 117 of hb/b (where hb is the height of the step and b is the to width of the step), a number of steps as 118 well as the distance from the beginning of the spillway have been calculated based on the 119 experimental measurements. Results illustrated that the best type of spillway in regard to design 120 and resistance against risk of the cavitation and avoiding from the concrete erosion is the stepped 121 spillway with sixth -stepped spillway. 122 The impacts of dimensions and the number of steps on the flow regime and cavitation in stepped 123 morning glory spillways investigated by Bordbar et al. [34] by using the experimental models. 124 Based on the experimental data of the cavitation phenomena, the eleven-stepped spillway with 125 equal height and width were proposed to avoid from minus static pressure. 126 Fadaei Kermani et al. [35] investigated two important factors influencing on the cavitation 127 damage risk including flow velocity and cavitation index on the morning glory spillways in 128 Shahid Abbaspour dam spillway in Iran. Results illustrated that based on these factors, the major 129 damage occurs at the end of chute areas. Also, the cavitation index factor provides better 130 predictions for the cavitation damage levels, than the minus pressure. This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4329747 Preprint not peer reviewed 5 131 Asadsangabi et al. [36] investigated maximum discharge coefficient and cavitation index in 132 shaft-spillways using Volume of Fluid (VOF) method and flow turbulence is modeled by “k-ε” 133 model. Based on experimental results, models were verified and discharge, velocity, pressure 134 and cavitation index for different inlet shapes were computed. The results showed that the VOF 135 approach can provide the appropriate results for solving the problems related to the cavitation 136 phenomena. 137 Parsaie et al. [23] simulated cavitation phenomenon along spillway's flip bucket of the Balaroud 138 dam using Flow-3D. The results of numerical modeling demonstrated that RNG turbulence 139 model has an appropriate performance for modeling the cavitation. Also, the minimum cavitation 140 index in physical modelling was about 0.85, and minimum cavitation index based on Flow 3D 141 results was about 0.665. It was deduced that due to high values of the water head through the 142 morning glory spillway, the static pressure achieves positive values and as a result, the cavitation 143 index was obtained than 0.45 which were indicated that due to increasing the water depth, the 144 risk of the cavitation is decreased significantly. 145 Morning glory spillway is commonly threated by the cavitation phenomena induced by the high 146 values of the velocity and low static pressure because of the performance of this hydraulic 147 structure. It is supposed that finding the safe zone and threated zone by cavitation due to 148 variating of the flow discharge is important item for avoiding and controlling the cavitation. 149 Present study carried out some experimental tests on the experimental models of the morning 150 glory spillway and validated a numerical model based on the experimental information. It is 151 predicted that the different components of the morning glory spillway such as intake of the 152 spillway, vertical shaft, bend pipe, and horizontal shaft were faced with the cavitation due to 153 achieving the requirements of the cavitation. Proposing the suitable shape of the components of 154 the morning glory spillway could reduce the statistic of the citation to zero. So, the cavitation 155 number of the semi- submerged flow which has the worst impact on the generation of the 156 cavitation with different ratio of D/R (D is the vertical and horizontal shaft diameter size and R is 157 the radius of the pipe bend of the morning glory spillway) were explored numerically and some 158 boundaries were proposed to design of the bend pipe of the morning glory spillway with lower 159 cavitation possibility. salehi etal (2023) tried to study the effect of of the pipe bend of the morning glory spillway on the cavitation number. They concluded that to prevent from the cavitation, the values of the cavitation number due to 18 different R/D as 0.55, 0.45, 0.35, and 0.25 were calculated by employing the validated numerical 19 model due to high danger of the cavitation based on the flow condition which was semi20 submerged condition. Results showed that due to D/R cavitation is negligible.

3- Methodology

In this research, a physical model, similar to the spillway model of the San Luis Fur by Dam located in the Central Valley of California, USA, has been selected. This model has been prepared with some changes in its dimensions and scale to conduct new tests. The specifications of the model are in table (1). Mentioned. Different types of vortex breakers were needed to perform different stages of the experiments. Compressed plastic (thick Teflon) with different thicknesses (thickness 19.5mm, 14mm and 210mm) was used to make the vortex breakers.

Table 1: General specifications of the dam and spillway physical model

Model specifications	length)	width)	height)	radius)	area)	volume)	slope
Physical model	۳۷۰/۰۰	۱۰۵/۰۰	۲۲۵/۰۰	---	---	---	۰
dam tank	۱۲۰/۰۰	۱۰۵/۰۰	۳۳۵۱۲	---	---	۱۰۰۰	۰
The right slope of the tank	۴۵۲۱۰	۲۶/۲۰	۷۵/۲۷	---	---	---	۰/۴
Five overflow models	---	---	۲۸/۲۰	۱۷/۵۰	۹۶۲/۱۱	---	۰
Ninety degree bend	---	---	---	۴۵۱۴۳	۲۹۷۶۸	---	۰
Dam water transfer tunnel	۲۱۴/۰۹	---	---	۷/۶۲	۴۵/۶۰	---	۰
Downstream reservoir	۳۶۵۵۷	۳۶۵۲۶	۳۶۵۲۶	---	---	۲۰۰۰	۰
Pentax pump	---	---	۱۲۰۰	---	---	۴۵۲۶۹	۰

4- Conclusion

4-1- Examining the tests related to the first spillway (control spillway with a non-step channel)

The control test (morning glory spillway test without vortex breaker) has been performed with various types of vortex breakers, based on different arrangements of 3, 4 and 6. It should be noted that in this collection: the range of changes of the measured flows varies from l/s 1.13 to l/s 3.9 for different experiments. The effect of eddies on the height of the water on the spillways, the arrangement of the eddies on the spillways is very high in the relation between Dubai and Height. For better understanding, Discharge -Height comparison chart is presented as Figure (1).

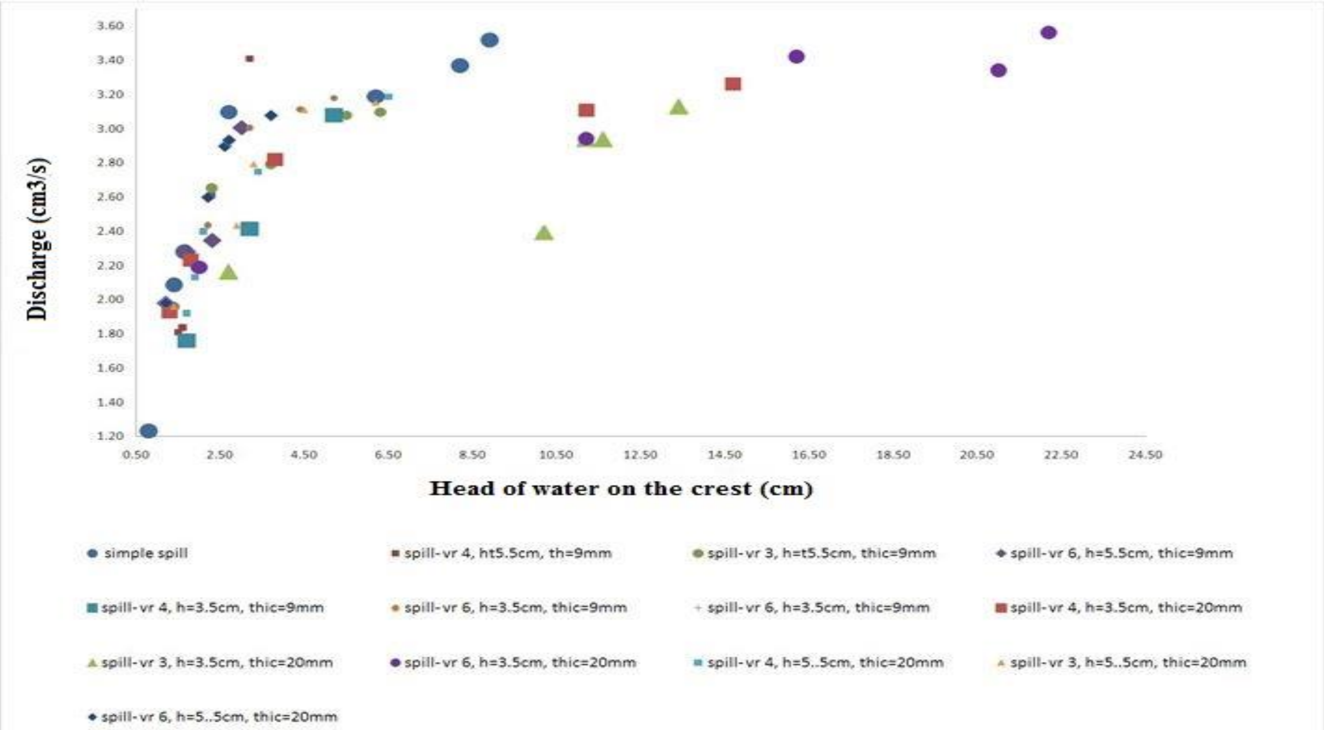

Figure 1: Discharge-Height diagram of Smooth spillway (without vortex braker 0 spillway with different types of eddies

As shown in figure (1), the flow-Height relationship related to the witness morning glory spillway tests is very different, such that the maximum amount of flow changes related to the experiment with the arrangement of 6 vortex breakers (vortex breaker with a height of 9 mm and a height of 3.5 cm and the lowest amount of changes is related to the experiment with the arrangement of 4 vortex breakers (vortex breakers with a height of 2.5 cm and a thickness of 9 mm). In this regard, it can be said that the arrangement of 6 blaes covers a larger range of flow changes with different heights of water on the spillway, but the arrangement of 4 does not have this scope of application. In the following, the characteristics of changes in piso metric pressure in tests with different types of vortex breakers are presented.

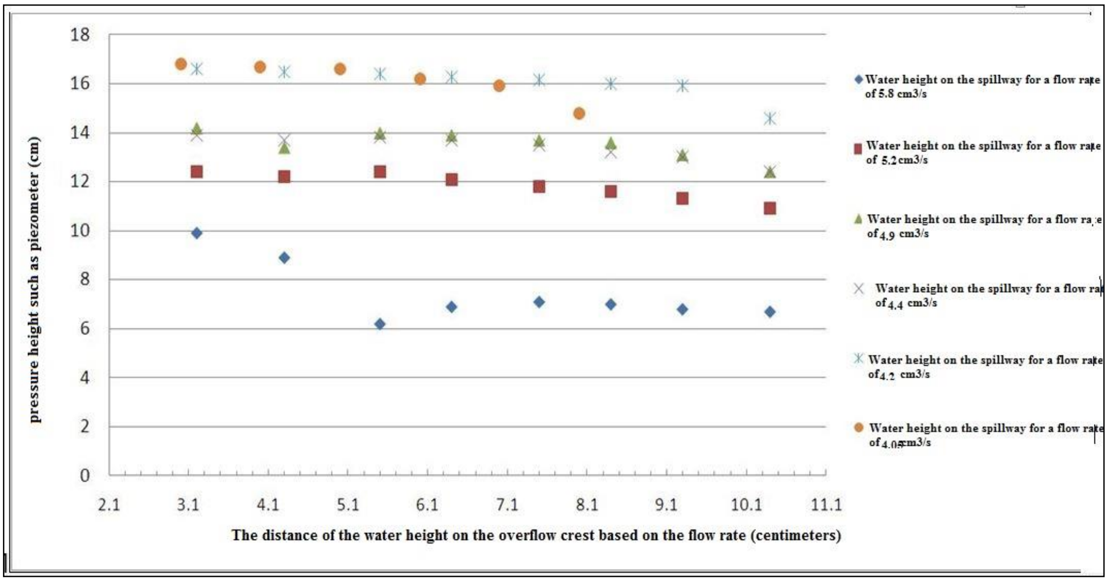

Figure 2: Diagram of pressure changes in Shahed morning glory spillway body with arrangement of 3 vortex breakers, height 2.5 cm and thickness 9 mm.

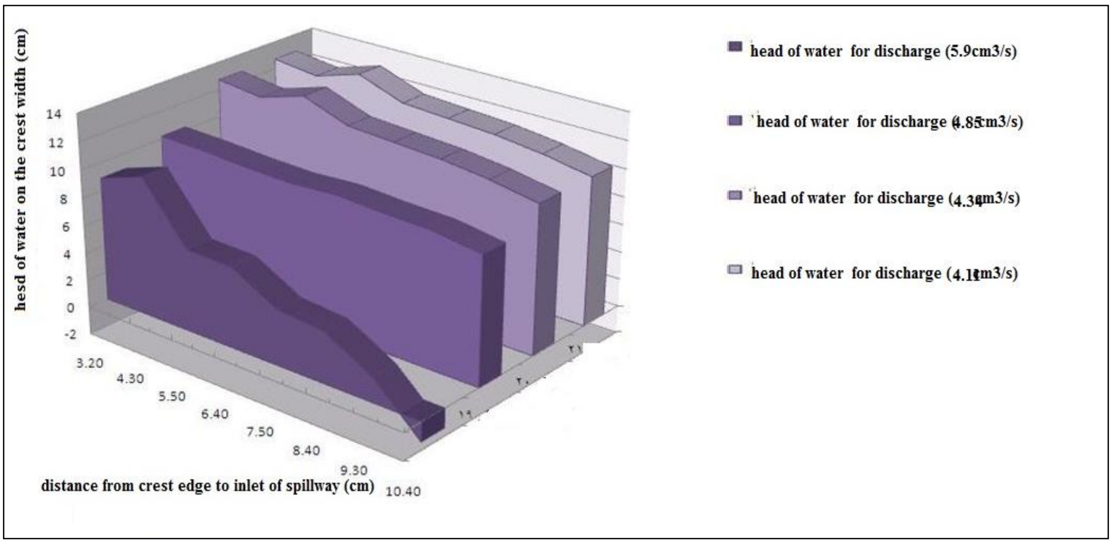

Figure 3: Diagram of pressure changes in Shahed morning glory spillway body with arrangement of 6 vortex breakers, height 2.5 cm and thickness 9 mm.

Based on figures (2) to (3), the use of eddies will have a great effect on the changes in the pressure of the morning glory spillway body, so that in the case of 4 eddies, the flow will flow in a small form on the morning glory spillway and the eddies do not have a significant effect. But with the increase in flow rate and water height, the flow regime will be completely different in such a way that the flow lines are regularly broken by the vortex breakers and prevent the creation of a vortex in the center of the Morning glory morning glory spillway. But with the increase in flow rate and absorption of 20% of the vortex breakers, the way the current passes becomes completely turbulent and the broken lines of the flow are completely mixed with the vortex state.

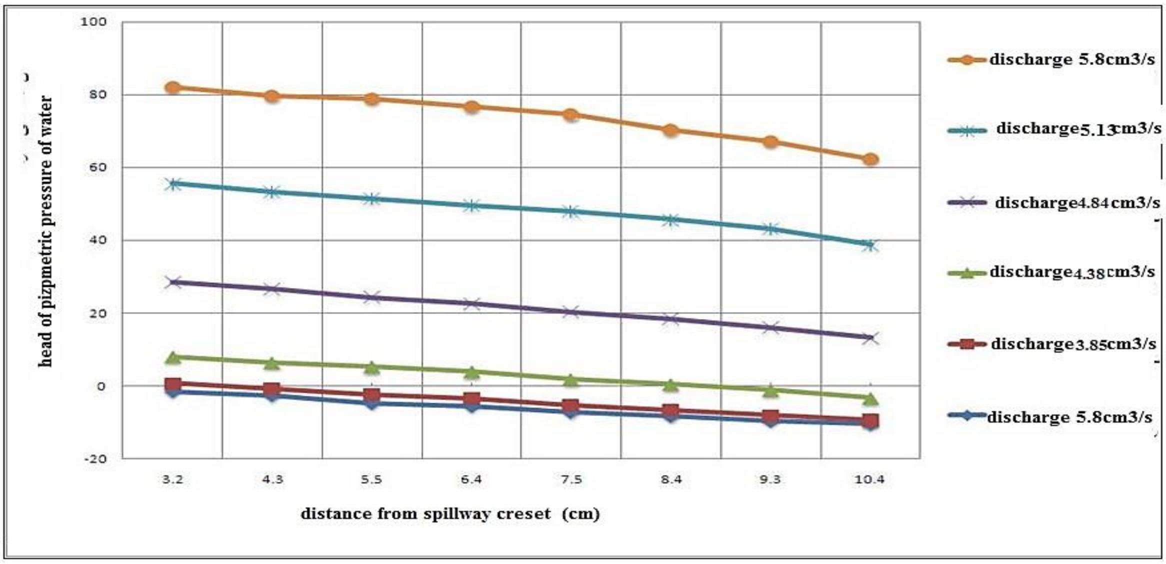

Figure 4: Diagram of pressure changes in the body of Smooth spillway (without vortex breaker 0 morning glory spillway with the arrangement of 3 vortex breakers, height 3.5 cm and thickness 20 mm.

In the investigation of the experiments, with the vortex breaker with 4 arrangement, the type of the vortex breaker is rectangular in shape with a height of 2.5 mm, a length of 2.7 mm, and a thickness of 9 mm, the behavior of the flow has significant changes, as in the initial state. After a small flow passes through the morning glory spillway -vortex breakers, it causes fundamental changes in the breaking of the flow lines, and with the gradual increase of the flow, it turns from a blade state to a progressive flow, and the effect of the vortex breakers performance increases greatly. In examining the effect of the vortex Breaker on the morning glory spillway coefficient.

Table (2) shows the effects of the presence of types of vortex breakers on the discharge coefficient.

Row	overflow type	H/R_s	Cd	n_v/c	l_v/c	t_v/c	C_v	C_x
1	1	0.08	0.85	0	0	0	1	1
2	1	0.0875	0.96	0.35/4	0.2	0.025	1.12	١
3	1	0.085	1.13	۰.۳۵/۳	۰.۲	۰.۰۲۵	1.32	١
٤	١	0.073	1.38	۰.۳۵/۶	۰.۲	۰.۰۲۵	1.62	١
4	1	0.07	1.39	۰.۳۵/۳	۰.۱۴	۰.۰۲۵	1.63	١
	١	0.078	1.18	۰.۳۵/۳	۰.۲	۰.۰۶	1.38	
5	1	0.079	1.14	۰.۳۵/۳	0.2	0.06	1.34	1
6	1	0.67	1.47	۰.۳۵/۳	0.2	0.06	1.72	1
7	1	15	0.67	0	0	0	1	1
8	1	0.17	0.54	0.35/4	0.2	0.025	0.81	1
9	1	0.31	0.23	۰.۳۵/۳	۰.۲	۰.۰۲۵	0.343	1
10	1	0.17	0.48	۰.۳۵/۶	۰.۲	۰.۰۲۵	0.716	1

4-2- Examining the experiments related to the second spillway (the control spillway with a non-stepped channel)

4-2-1- Investigating the relationship between Height- Discharge in the second spillway

In order to check the second spillway (6-step spillway), which has 2 cm wide steps, the results were presented in the following figures.

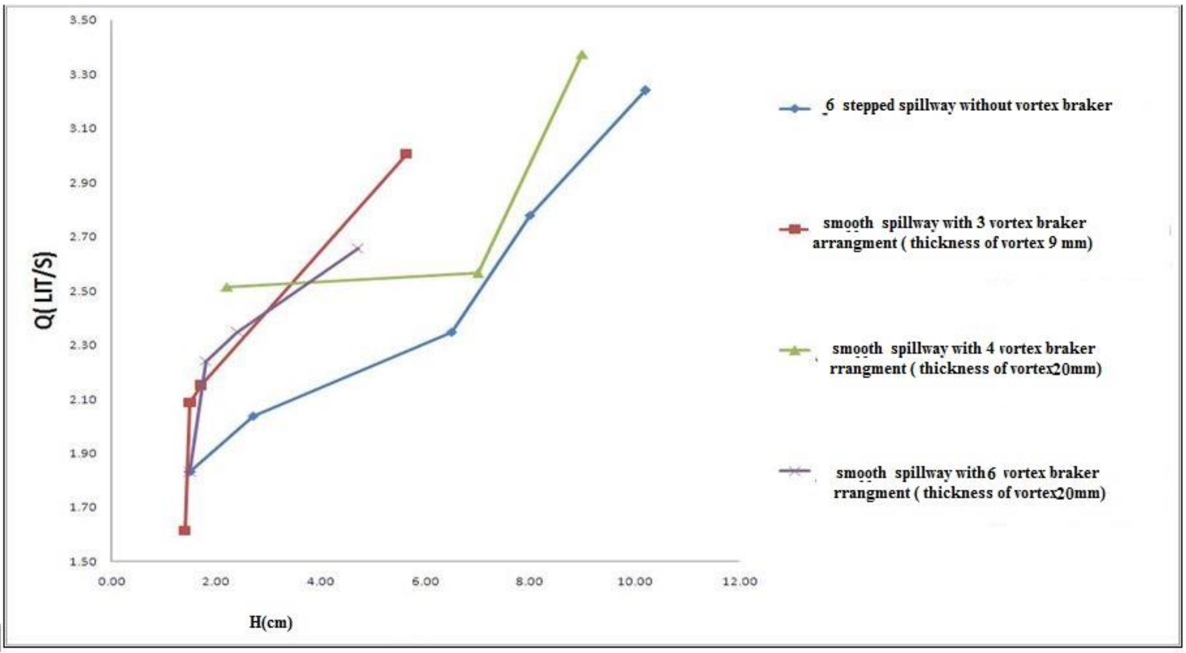

Figure 5: The relationship between discharge and spillway with a 6-step channel with and without a vortex breaker (vortex breaker with a height of 3.5 cm and a thickness of 9 mm)

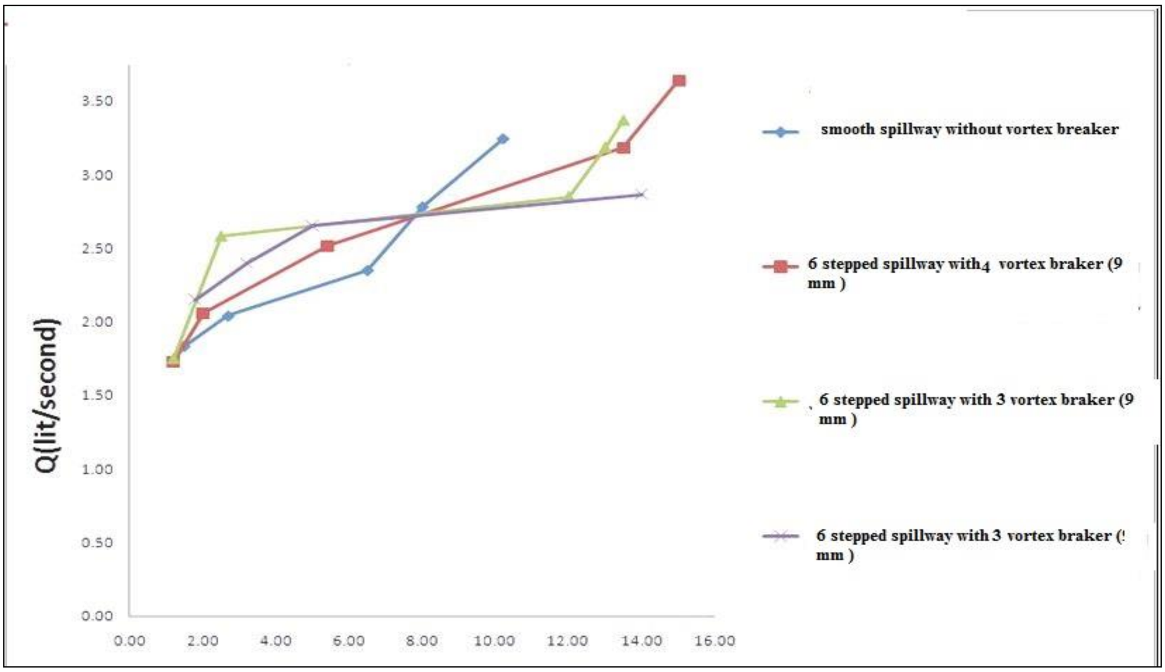

Figure 6: Discharge-Height morning glory spillway relationship with 6-step channel with and without vortex breaker (vortex breaker with a height of 3.5 cm and a thickness of 20 mm)

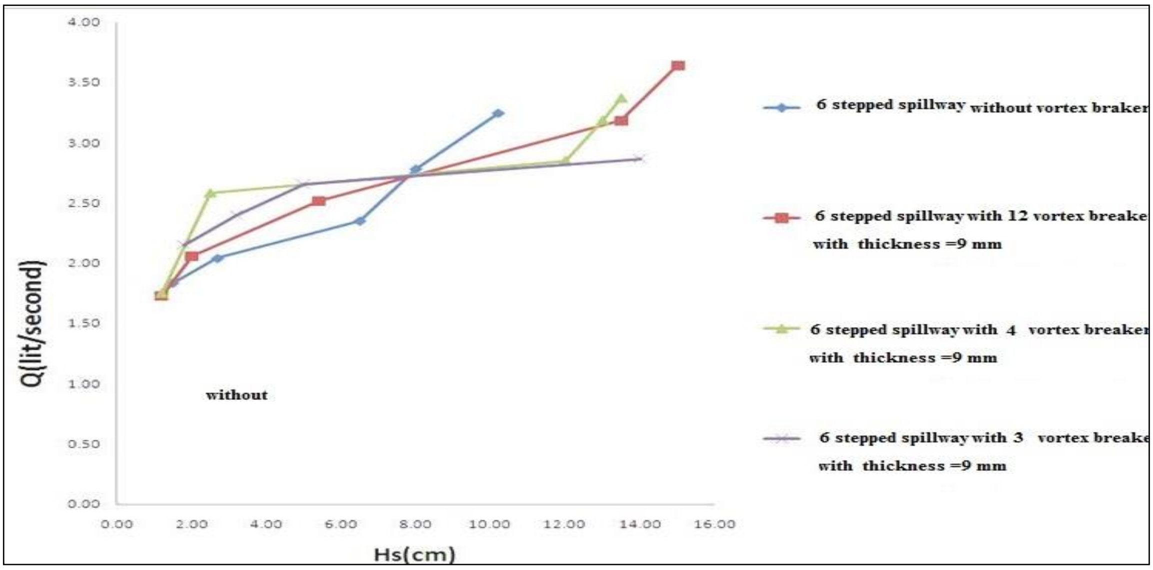

Figure 7: Discharge-Height morning glory spillway relationship with 6-step channel with and without vortex breaker (vortex breaker with a height of 5.5 cm and a thickness of 20 mm)

Based on the observations in figures (5) to (7), due to the use of the vortex breaker, noticeable changes in the discharge-flow relationship can be observed in the morning glory spillway s, and the biggest changes are related to the vortex breaker with a height of 3.5 mm and a thickness of 9 mm. The lowest increase in flow rate is the effect of using a vortex breaker with a height of 5.5 cm and a thickness of 9 mm. It should be noted that the highest range of height changes in the relationship between Discharge and Eschel is related to the test results with a 3-way arrangement and a vortex breaker with a height of 5.5 cm and a thickness of 20 mm. The changes are related to the specific characteristics of the flow in these morning glory spillway s, which will be discussed further.

4-2-2- Investigating the piezo metric pressure relationship in the second spillway:

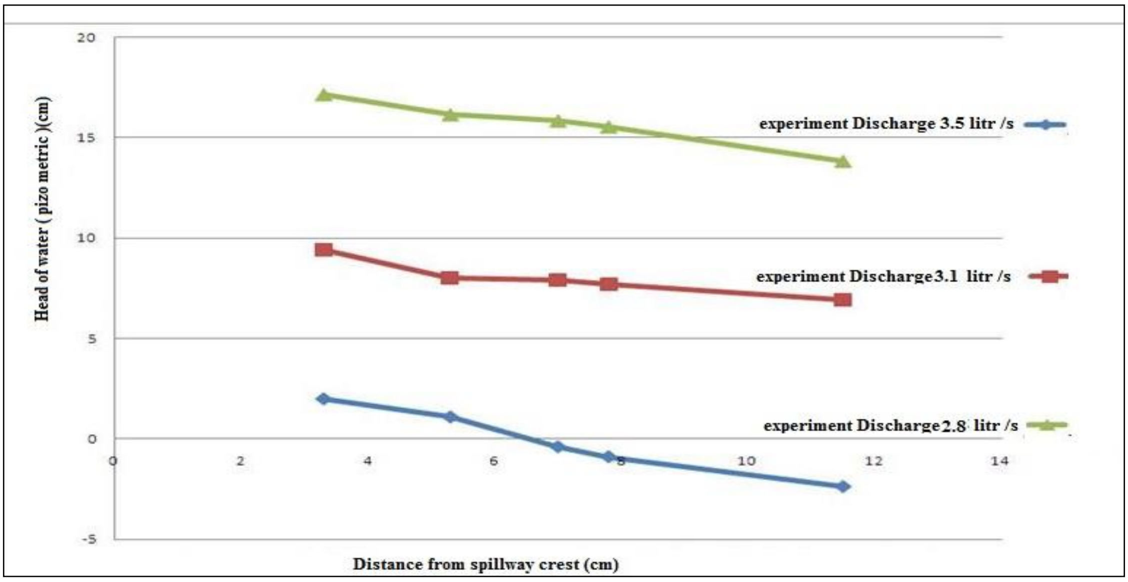

Figure 8: A view of the pressure changes in the 6-step morning glory spillway test with 3 vortex breakers (height 3.5 cm and thickness 20 mm)

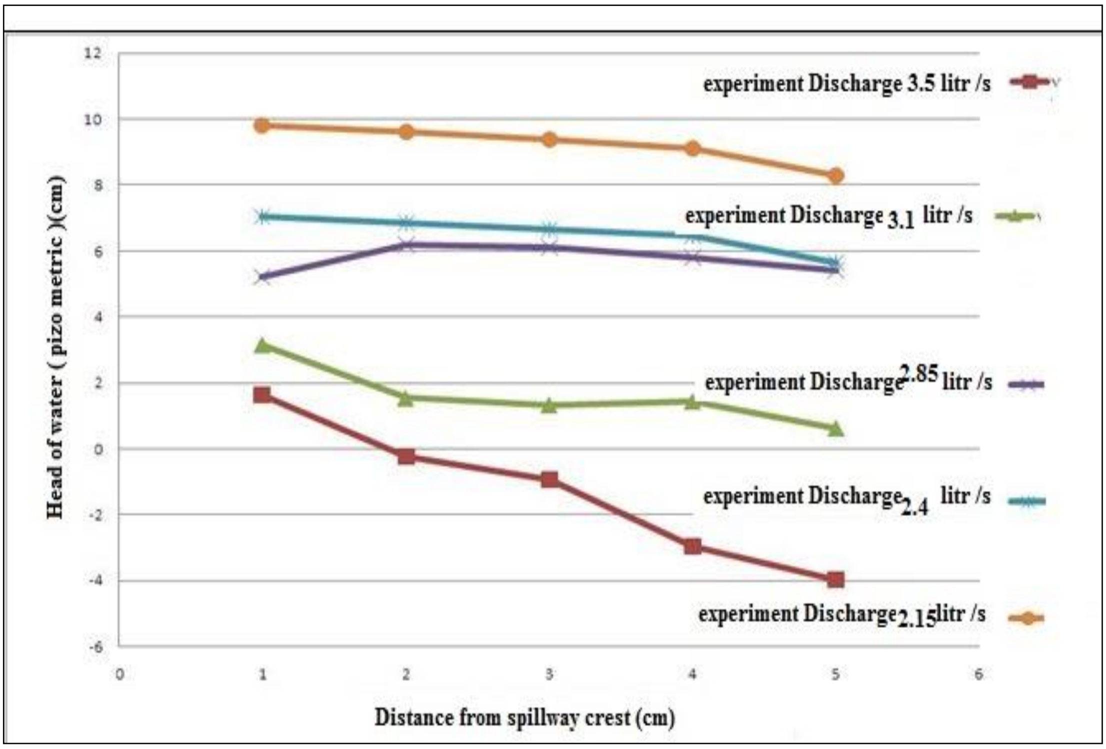

Figure 9: A view of the pressure changes in the 6-step morning glory spillway test with a 3-piece arrangement of vortex breakers (height 3.5 cm and thickness 20 mm)

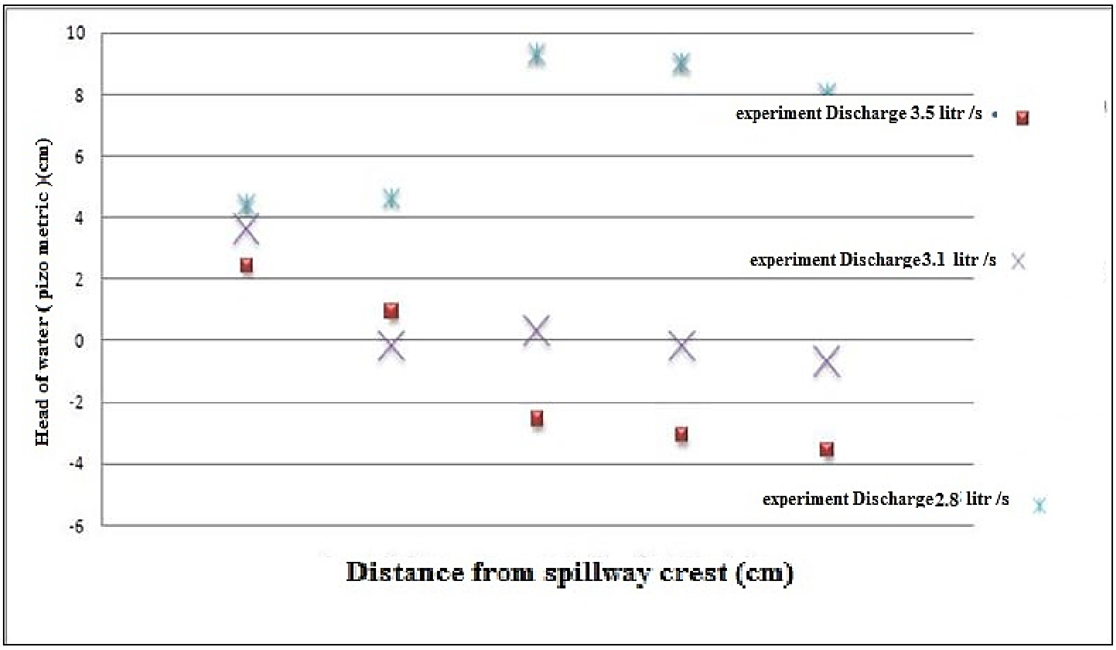

Figure 10: A view of the pressure changes in the 6-step Morning glory spillway morning glory spillway test with an arrangement of 3 vortex breakers (height 3.5 cm and thickness 9 mm)

Based on the observations, in figures (8) to (10), the pressure changes in different types of flow rates and series of vortex breakers are completely different from each other, which shows the extent of their changes. In terms of comparing the fluctuations of pressure changes in the series of experiments with 3 vortex breakers are very high, but in the series of experiments with 6 vortex breakers, these changes are less, which is due to the existence of more stability in the series of experiments with 3 vortex breakers. In other words, the turbulence in 3-series tests is more than 6-series tests, which can be attributed to the complete failure of the flow lines during the test.

In general, it can be said that due to the presence of a stepped channel and a vortex breaker, the flow is completely different compared to a smooth morning glory spillway. which looked for the difference in the effect of loss caused by the failure of flow lines and its complexity. With the increase of the flow rate, the fine motion turns into a process state, and the effect of the vortex breakers becomes more complicated due to the increase of the drop, and the state of boiling and instability of the flow is observed more.

Table 3: Investigating the effects of the vortex breaker on the flow rate passing through the 6-step spillway

Row	overflow type	Dubai	H/Rs	Cd	r/c	L/c	t/c	L/c	C1	C2
1.00	2.00	2.03	0.17	0.59	0.00	0.00	0.00	0.00	1.00	0.69
2.00	2.00	1.96	0.09	1.30	0.35/4	0.20	0.03	0.06	1.38	0.80
3.00	2.00	1.96	0.10	0.61	0.35/3	0.20	0.03	0.06	1.32	0.41
٤.٠٠	2.00	1.97	0.13	0.63	0.35/3	0.20	0.03	0.06	1.62	0.28
٥.٠٠	2.00	1.99	0.11	0.78	0.35/4	0.14	0.03	0.06	1.12	0.73
6.00	2.05	2.05	0.10	1.16	0.35/3	0.20	0.06	0.06	1.70	0.46

4-2-3. Investigating the thickness of the vortex breaker on the hydraulics of the flow passing over the spillway

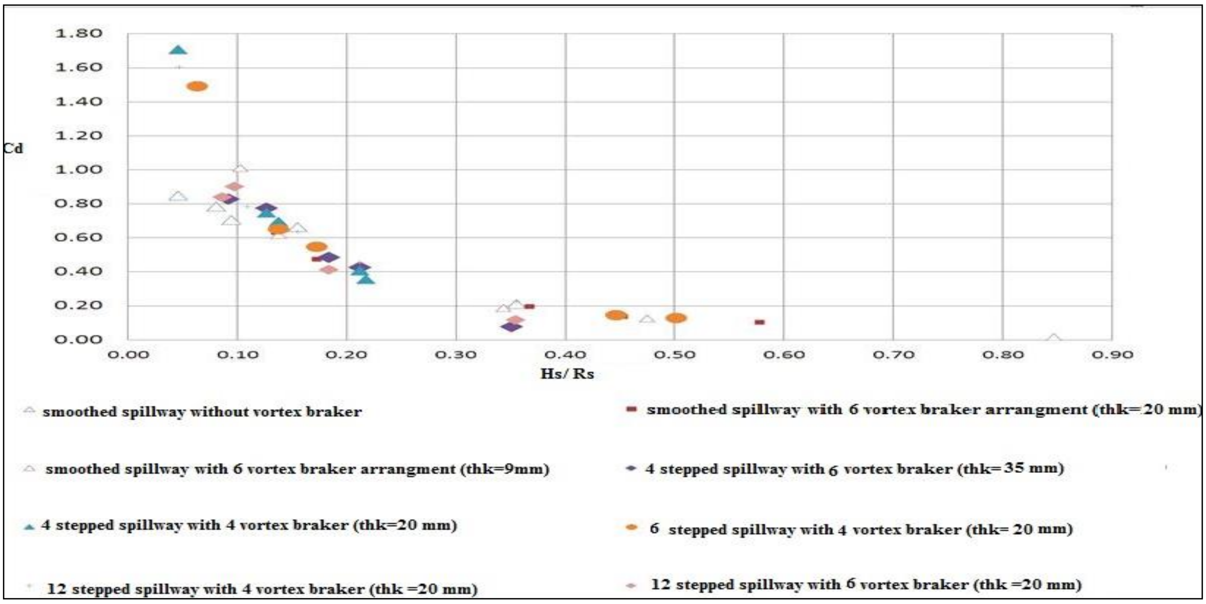

Figure 11: Examining the relationship between discharge coefficient and intake ratio in different morning glory spillway s (arrangement of 6 vortex breakers with a height of 3.6 and a thickness of 9 and 20 mm)

Based on this figure, although the thickness of the vortex breaker does not have any effect on the flow, it does not have a significant positive effect, and in morning glory spillway s with a stepped channel, it has the greatest effect on the morning glory spillway of 4 steps with a thickness of 9 mm, and the increase in thickness to 20 mm reduces the flow rate. Passage flows at the rate of 8%.

4-2-4- Investigating the type of vortex breaker on the hydraulics of the flow passing over the spillway.

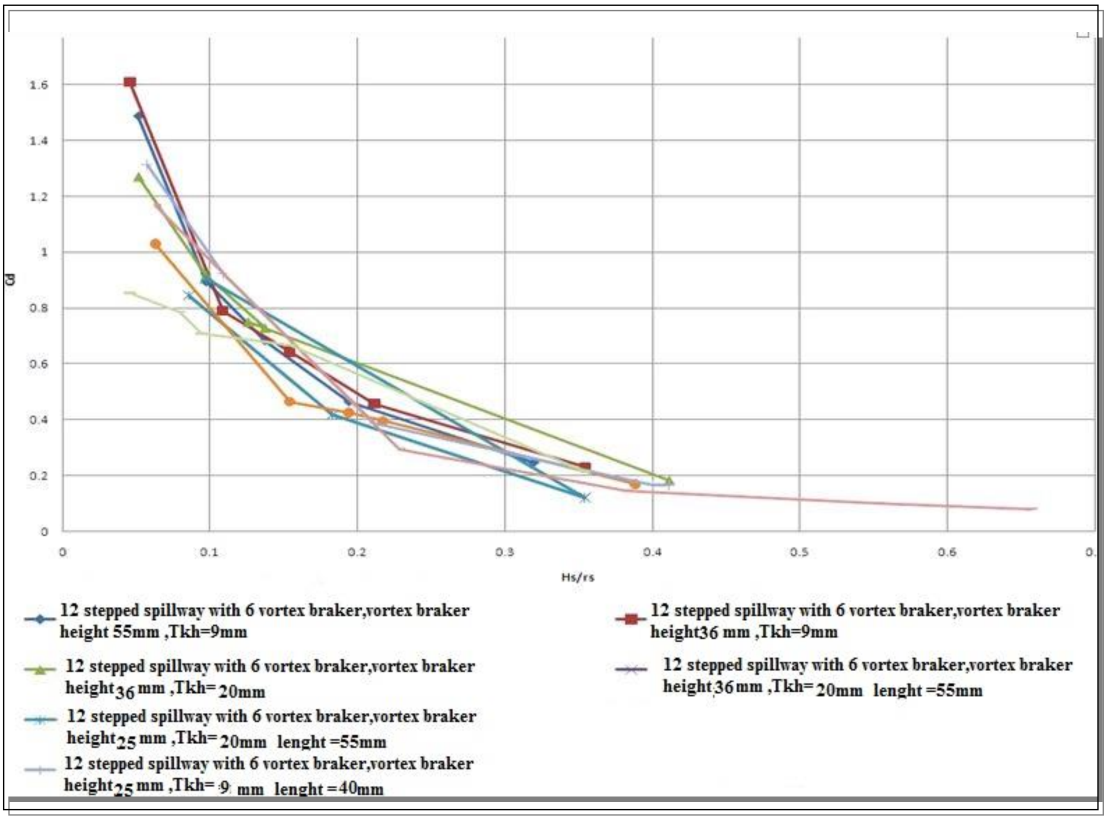

Figure 12: Specifications related to the discharge coefficient with types of vortex breakers on the 12-step Morning glory spillway spillway and comparison with the control spillway.

According to figure (12), the changes of the eddy have many effects on the amount of flow passing through the spillway. For example, the effect of the arrangement of 6 eddies with a height of 3.6 cm and a thickness of 9 mm, which causes the roughness coefficient It is 39%. The lowest effect is related to the vortex breaker with a length of 2.5 cm, a height of 2.5 cm, and a thickness of 20 mm.

4-2-5- Examining this figure, the following results are obtained:

1- Increasing the length of the vortex breaker does not have a significant effect on the morning glory spillway discharge coefficient. The amount of this increase in flow rate is equal to 7.6% compared to the morning glory spillway coefficient of 12 steps without vortex breaker.

2- Increasing the thickness does not have a great effect on the amount of morning glory spillway discharge.

3- The high height of the morning glory spillway does not have a positive effect on the discharge coefficient. (It has an effect, but the effect is small).

5. Investigating the effect of types of vortex breakers on the types of flow passing through the spillway

Based on the conducted tests, the flow control on the Morning glory spillway with the increase of the flow rate, which increases with the increase of the water height on the spillway crest, will change from the flow control mode to the crown control mode and finally it will turn into the absorption mode. For better understanding, the table below shows the place of flow change from morning glory spillway control to orifice control with different infiltration ratio with arrangement of 6 types of vortex breakers for morning glory spillway types.

Table 4: Flow changes from morning glory spillway control mode to orifice control in relation to absorption ratio

Row	morning glory spillway type	vortex type	Channel Type	stair formation	Hs/Rs
1	**observed**	-	**Smooth**	-	**0.31**
2	**observed**	**9 mm and 3.5cm height**	**Smooth**	**6-fold**	**0.18**
3	**observed**	**20 mm and 3.5cm height**	**Smooth**	**6-fold**	**0.23**
4	**observed**	**20 mm and 5.5cm height**	**Smooth**	**6-fold**	**0.27**
5	**2**	-	**6 steps**	-	**0.38**
6	**2**	**9 mm and 3.5cm height**	**6 steps**	**6-fold**	**0.2218**
7	**2**	**20 mm and 3.5cm height**	**6 steps**	**6-fold**	**0.21**
8	**2**	**20 mm and 5.5cm height**	**6 steps**	**6-fold**	**0.245**

Based on the above table, the changes in absorption ratio in the control conversion mode from morning glory spillway to orifice with types of vortex breakers are different based on the change of flow type and type of vortex breaker. As it is known, the use of the vortex breaker causes a change in the process of converting and controlling the flow from the morning glory spillway to the orifice. The height of the vortex breaker causes a decrease in the absorption ratio in the state of flow conversion from morning glory spillway to orifice. The reason for this can be attributed to better flow through the morning glory spillway. According to the presented specifications, the general conclusion can be considered in the form of tables (5) to (8).

Table 5: Investigation of the general effects of the vortex breaker on smoothed spillway

Row	morning glory spillway type	vortex type	Thickness	Height	Count	Length	Effect Percentage
1	**simple (without step chamber)**	**Short**	**20mm**	**3.5cm**	**6**	**5.2**	**Increase 17.8**
2	**simple (without step chamber)**	**Short**	**9mm**	**3.5cm**	**4**	**5.2**	**Decrease 16**
3	**simple (without step chamber)**	**Short**	**9mm**	**3.5cm**	**3**	**5.2**	**Increase 12.2**
4	**simple (without step chamber)**	**Tall**	**20mm**	**5.2cm**	**6**	**7**	**Increase 13.7**
5	**simple (without step chamber)**	**Tall**	**9mm**	**5.2cm**	**3**	**7**	**Increase 5.8**

Table 6: Study the overall effects of the vortex breaker on the witness morning glory spillway

Row 1	morning glory spillway type	vortex type	Thickness	Height	vortex braker location on the crest	Length	Effect Percentage
1	6 steps	Short	9mm	5.2cm	6	7	Increase 13
2	6 steps	Short	9mm	5.2cm	3	7	Increase 8
3	6 steps	Short	20mm	3.5cm	6	5	Increase 3.5
4	6 steps	Short	20mm	3.5cm	3	5	Increase 2.3

Table7: General comparison of spillways in a specific flow rate

Row	overflow type	Dubai	H / R_S	Cd	n_v / d	l_v / d	t_v / d	l_c / d	C_{1V}	C_{2v}
1	1	2	0.08	0.87	0	0	0	0	1	1
2	1	1.98	73	1.38	0.35/6	0.2	0.025	0	1.62	1
3	2	2.03	0.17	0.59	0	0	0	0	1	0.69
4	2	1.97	0.13	0.63	0.35/3	0.2	0.025	0.06	1.62	0.28
5	3	2.05	0.08	0.79	0	0	0	0.086	1	0.929
6	3	2.04	0.079	0.81	0.35/3	0.2	0.025	0.086	1.32	0.543
7	4	2.05	0.102	0.69	0	0	0	0.11	1	0.81
8	4	2.06	0.12	0.67	0.35/3	0.2	0.025	0.11	1.32	0.449
9	5	2.01	0.08	0.86	0	0	0	0.028	1	1.02
10	5	2.03	0.098	0.89	0.35/6	0.2	0.025	0.028	1.62	0.398

Table 8: Comparison of vortex breakers with different shapes in Morning glory spillway spillway with 4 steps

Row+U 43:AE4 9	overflo w type	Dubai	H / R_S	Cd	n_v / d	l_v / d	t_v / d	l_c / d	C_{3V}	vortex shape
1	3	2.25	0.09	0.41	0	0	0	0.086	1	-
2	3	2.26	0.092	0.81	0.35/4	0.2	0.025	0.086	1.97	trapezoid
3	3	2.26	0.172	0.44	0.35/4	0.142	0.025	0.086	1.07	trapezoid
4	3	2.27	0.141	0.62	0.35/4	0.142	0.06	0.086	1.51	trapezoid
5	3	2.26	0.12	0.69	0.35/4	0.142	0.06	0.086	1.64	ogee shapes
6	3	2.26	0.096	0.605	0.35/4	0.142	0.06	0.086	1.47	Rectangular

5- Results

In the series of experiments conducted in connection with Smooth spillway (without vortex braker 0 morning glory spillway and types of vortex breakers:

The use of a long vortex breaker has more reasonable and appropriate results than other modes, and in the arrangement of 3, it has a better arrangement than other arrangements of the placement of the vortex breakers. In general, it can be stated that in the analysis of these relations, series 3 and 6 have better results than the results of the arrangement of 4, and in the examination of the flow coefficients, it is clear that the highest amount of increase in flow is related to the results of the vortex breaker test with the arrangement of 6 and The vortex breaker has a height of 3.5 cm and a thickness of 20 mm, which increases the flow rate by 17.8 percent, and the lowest effect is related to the results of the morning glory spillway with 4 vortex breakers of 9 mm and a thickness of 3.5 mm, which reduces the effect of the flow rate. The passing rate is close to 16%.

In the Smooth spillway (without vortex braker 0 spillway: in the first case, when the height of the water entering the spillway is low, the flow passes in the form of a blade and the control is from the side of the spillway crown. Then by increasing the height of the water to the amount of am2.6 (), which is the power (H is the height of the water on the morning glory spillway , Rs is the entrance radius of the morning glory spillway). The movement of the flow changes from a blade state to a vortex state, which creates a great vortex in the end part of the morning glory spillway body, and the mixing state of the water in this state is partially a backflow state.

In this type of morning glory spillway, when the flow rate reaches 2.95 hc/s. Complete absorption is created, in other words, according to the accepted studies, the changes in the type of flow that is usually created in this morning glory spillway is created in this state. that this event changes the state of a large and turbulent vortex into a small and spiral vortex flow along with an increase in water height and ultimately causes the stability of the entire flow.

The use of eddies will have a great effect on the changes in the pressure of the morning glory spillway body, so that in the arrangement of 4 eddies, the flow first flows in a small way on the morning glory spillway and the eddies do not have a significant effect, but with the increase in flow rate and water height, the flow regime It will be completely different in that the flow lines are regularly broken by the vortex breakers and prevent the creation of a vortex in the center of the lotus morning glory spillway . But with the increase in flow rate and absorption of 20% of the vortex breakers, the way the current passes becomes completely turbulent and the broken lines of the flow are completely mixed with the vortex state. In the middle part of the morning glory spillway , a large vortex is created, which causes strong turbulence in the flow.

It is important to increase the thickness of the vortex breakers, that with a significant increase in the thickness of the vortex breakers, the pressure in the morning glory spillway body changes, but these changes have less effects than the height change. But it is worth mentioning that in the state before the full absorption of the vortex breakers due to the reduction of the flow passing surface (wetted surroundings) in the arrangement of 4 vortex breakers on the morning glory spillway crest, changes and a sudden drop in pressure can be seen in the middle parts, which is because The change of the flow regime from the crown control mode to the aperture control mode and the semi-effective breaking of the flow lines by the vortex breakers.

5-1- Investigating the effect of vortex breaker and conduit on the hydraulics of the 12-story Morning glory spillway

For example, using an morning glory spillway with 6 steps reduces the flow coefficient by 16%, and an morning glory spillway with 12 steps reduces the morning glory spillway coefficient by 23%.

The impact of the vortex breakers on the discharge coefficient is very high, such that this coefficient has a positive effect for the morning glory spillway with a stepped channel.

For example, for a spillway with a 4-step channel, the rate of flow increase compared to the control spillway with a vortex breaker shows an increase of 18% and compared to the flow rate passing through the Smooth spillway (without vortex braker 0 spillway without a vortex breaker, it shows an increase of 3.7%.

The lowest amount of roughness coefficient is related to Morning glory morning glory spillway of 12 steps in the case of experiments without vortex breaker, but the highest coefficient is related to the results obtained from the control morning glory spillway. Based on the experiments related to the morning glory spillway with the vortex breaker, the lowest discharge coefficient is related to the 12-step morning glory spillway, then it is related to the 3rd, 4th, and 6th morning glory spillway.

The thickness of the vortex breaker, although it does not have any effect on the flow, but it does not have a significant positive effect, and in morning glory spillway s with a stepped channel, it has the greatest effect on the morning glory spillway of 4 steps with a thickness of 9 mm. The amount of 8% flows. Of course, it should be noted that the effect of the 20 mm thick vortex breaker on the flow compared to the drop coefficient of the morning glory spillway shows a decrease of the drop coefficient by 6%.

The changes of the eddy have many effects on the amount of flow passing through the spillway. For example, the effect of the arrangement of 6 eddies with a height of 3.6 cm and a thickness of 9 mm. which causes a roughness coefficient of 39%. The lowest effect is related to the vortex breaker with a length of 2.5 cm, a height of 2.5 cm, and a thickness of 20 mm.

References

[1] N. Rajaratnam, A.Mainali, C. Y. Hsung, Observations on flow in vertical dropshafts in urban 627 drainage systems, Journal of Environmental Engineering, 123(5) (1997), 486-491. 628

[2] S. C. Jain, Free-surface swirling flows in vertical drop shaft, Journal of Hydraulic 629 Engineering ,113(10) (1987): 1277-1289. 630

[3] D. L. Bagheri, and W. H. Hager, Energy dissipators, hydraulic structures design 631 manual, IAHR, Balkema, Rotterdam, the Netherlands, (1995). 632

[4] R. Shemshi, and S. Kabiri-Samani, Swirling flow at vertical shaft spillways with circular 633 piano-key inlets, Journal of Hydraulic Research, 55(2) (2017), 248-258. 634

[5] S.C. Jain, Tangential vortex-inlet, Journal of hydraulic engineering, 110(12) (1984), 1693- 635 1699. 636

[6] W. H. Hager, Vortex drop inlet for supercritical approaching flow, Journal of Hydraulic 637 Engineering, 116(8) (1990), 1048-1054. This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4329747 Preprint not peer reviewed 21 638

[7] M. C. Quick, Analysis of spiral vortex and vertical slot vortex drop shafts, Journal of 639 Hydraulic Engineering, 116(3) (1990), 309-325. 640

[8] X. L. Dong, K. L. Yang, X. L. Guo, Y. X. Guo, Hydraulic mechanism and application of 641 swirling device in morning glory shaft spillway, Journal of Hydraulic Engineering, (2011), 1. 642

[9] A. Kasra, A. Khosrojerdi, H. Babazadeh, Cavitation Risk through the Bottom Outlet of the Dam Using Numerical Solution of Ansys Model, JWSS-Isfahan University of Technology, 26(1) (2022), 195-209.

[10] P. Wu, X. Wang, W. Lin, L. Bai, Acoustic characterization of cavitation intensity: A review, Ultrasonics Sonochemistry, 82 (2022), 105878.

[11] Z. P. Liu, X. L. Guo, Q. F. Xia, H. Fu, T. Wang, X. L. Dong, Experimental and numerical investigation of flow in a newly developed vortex drop shaft spillway, Journal of Hydraulic Engineering, 144(5) (2018), 04018014.

[12] M. Haghbin, A. Sharafati, R. Aghamajidi, S. B. H. S. Asadollah, M. H. M. Noghani, M. L Jalón, Determination of discharge coefficient of stepped morning glory spillway using a hybrid data-driven method, Flow Measurement and Instrumentation, 85 (2022), 102161.

[13] M. Chitsazan, and H. R. Ghafouri, Optimization of Anti-vortex Blades Geometry in Morning Glory Spillways by Numerical simulation, Engineering, Environmental Science, (2022). https://doi.org/10.21203/rs.3.rs-1685709/v1.

[14-1] S. Radmanesh, A. Bazaee, R. Aghamajidi, Calculating the overflow coefficient of stepped and non-Stepped morning glory spillway and investigating its behavior using anti vortex blades, Civil and Project Journal, 4(2) (2022).

[14-2] R. Aghamajidi,(2013) Computerized simulation of hydraulic behavior of shaft spillway vortex breaker on crest and semi long stepped chamber throat, Technical Journal of Engineering and Applied Sciences. Issu23. 3325-3332. https://scholar.google.com/citations?view_op=view_citation&hl=en&user=u9WtUQs8WkUC&cstart=20&pagesize=80&citation_for_view=u9WtUQs8WkUC:L8Ckcad2t8MC

[15] S. Esmaeilizadeh, T. Mirzavand, Effect of deflector and aeration on the discharge coefficient of submerged flow of morning glory spillways, Journal of Dam and Hydroelectric Powerplant, 8(31) (2022), 62-74.

[16] S. T. Maynord, General Spillway Investigation; Hydraulic Model Investigation (No. WES/TR/HL-85-1), (1985)

[17] USBR, Design of small dams, Water Resources Technical Publication Series, (1987).

[18] C. H. Zhao, D. Z. Zhu, S. K. Sun, Z. P. Liu, Experimental study of flow in a vortex drop shaft, Journal of Hydraulic Engineering, 132(1) (2006), 61-68.

[19] C. A. Fattor, and J. D. Bacchiega, Design conditions for morning-glory spillways: application to potrerillos dam spillway, In Advances in Water Resources and Hydraulic Engineering, Springer, Berlin, Heidelberg. (2009), (2123-2128).

[20] G. Christodoulou, A. Mavrommatis, T. Papathanassiadis, Experimental study on the effect of piers and boundary proximity on the discharge capacity of a morning glory spillway, In 1st IAHR European Congress, Edinburgh, Scotland, (2010).

[21] L. Savic, R. Kapor, V. Kuzmanovic, B. Milovanovic, Shaft spillway with deflector downstream of vertical bend, In Proceedings of the Institution of Civil Engineers-Water

Management, 167(5) (2014), 269-278. This preprint research paper has not been peer reviewed. Electronic copy available at: https://ssrn.com/abstract=4329747 Preprint not peer reviewed 22 676

[22] A. salehi, moghadam: (2023) Effect of the pipe bend of the morning glory spillway on the cavitation number.

[23] A. Parsaie, S. Dehdar-Behbahani, A. H. Haghiabi, Numerical modeling of cavitation on 679 spillway's flip bucket, Frontiers of Structural and Civil Engineering 10(4) (2016), 438-444. 680

[24] J. J. Cassidy, Irrotational flow over spillways of finite height, University of Missouri681 Columbia, (1965). 682

[25] M. Ikegawa, and K. Washizu, Finite element method applied to analysis of flow over a 683 spillway crest, International Journal for Numerical Methods in Engineering, 6(2) (1973), 179- 684 189. 685

[26] P. L. Betts, A variational principle in terms of stream function for free-surface flows and its 686 application to the finite element method, Computers & Fluids, 7(2) (1979), 145-153. 687

[27] B. M. Savage, and M. C. Johnson, Flow over ogee spillway: Physical and numerical model 688 case study, Journal of hydraulic engineering, 127(8) (2001), 640-649. 689

[28] N. R. Olsen, and H. M. Kjellesvig, Three-dimensional numerical flow modelling for 690 estimation of spillway capacity, Journal of Hydraulic Research, 36(5) (1998), 775-784. 691

[29] W. R. Fiedler, Performance of spillway structures using Hoover dam spillways as a 692 benchmark, In Hoover Dam: 75th Anniversary History Symposium Fluent User Manual, 693 Sheffield, UK. (2010) (267-287) 694

[30] T. J. Alfatlawi, and H. I. Alshaikhli, Prediction the coefficient of discharge for stepped 695 morning glory spillway using ANN and MNLR approaches, International Journal of Civil and 696 Environmental Engineering, 37(2) (2015), 1701-8285. 697

[31] J. Liu, D. Nissim, J. Thomas, Equity valuation using multiples, Journal of Accounting 698 Research, 40(1) (2002), 135-172. 699

[32] H. T. Falvey, Cavitation in chutes and spillways, Denver: US Department of the Interior, 700 Bureau of Reclamation, (1990) 701

[33] R. Aghamajidi, H. M. Jahromi, H. Seghi, H. A. Kashkoi, Study effect of guide pier and 702 stepped chamber on flow regime of morning glory spill way, International Journal of Agriculture 703 and Crop Sciences (IJACS), 6(9) (2013), 493-500. 704

[34] A. Bordbar, H. Mousavi Jahromi, M. ShafaeiBajestan, H. Sedghi, Step effects investigation 705 on the flow regime and cavitation in stepped morning glory spillways, World Applied Sciences 706 Journal, 10(9) (2010), 1024-1031. 707

[35] E. F. Kermani, G. A. Barani, M. Ghaeini-Hessaroeyeh, Investigation of cavitation damage 708 levels on spillways. World Applied Sciences Journal, 21(1) (2013), 73-78. 709

[36] F. Asadsangabi, N. Talebbeydokhti, M. Rahnavard. Two phase flow modeling in shaft710 spillways using volume of fluid (VOF) method. Iranian Journal of Science and Technology, 711 Transactions of Civil Engineering, 38(C1) (2014), 99. This preprint research paper has not been peer

reviewed. Electronic copy available at: https://ssrn.com/abstract=4329747 Preprint not peer reviewed 23 712

[37] P. K. Swamee, S. K. Pathak, and M. Ghodsian, Viscosity and surface tension effects on 713 rectangular weirs, The ISH Journal of Hydraulic Engineering (2001) 7(2), 45-50. 714

[38] A. H. Azimi, N. Rajaratnam, D. Z. Zhu, “Water surface characteristics for submerged 715 rectangular sharp-crested weirs, Journal of Hydraulic Engineering, (2016) 142(5): 06016001-9. 716

[39] S.Salehi, and A. H. Azimi, Discharge characteristics of weir-orifice and weir-gate 717 structures, Journal of Irrigation and Drainage Engineering, 145(11) (2019): 04019025. 718

[40] A. H. Azimi, and S. Salehi, Hydraulics of flow over full-cycle cosine and rectangular sharp719 crested weirs, Canadian Journal of Civil Engineering, 49(6) (2022), 954-968. 720

[41] S. Salehi, A. Mahmudi Moghadam, K. Esmaili, Flow regimes of submerged rectangular 721 sharp-crested weirs in sand bed channel, Sadhana, 48(6) (2022), 58. 722

[42] S. Salehi, A. H. Azimi, H, Hydraulics of sharp-crested weir culverts with downstream 723 ramps in free-flow partially, and fully submerged-flow conditions. Irrigation Science, 39(2) 724 (2021): 191-207. 725

[43] S. Salehi, A. Mostaani A. H. Azimi, Experimental and Numerical Investigations of Flow 726 over and under Weir-Culverts with a Downstream Ramp. Journal of Irrigation and Drainage 727 Engineering, 147(7) (2022), pp.04021029. 728

[44] D. C. Wilcox, Reassessment of the scale-determining equation for advanced turbulence 729 models, AIAA journal, 26(11) (1988), 1299-1310. 730

[45] V. Yakhot, and L. Smith, The renormalization group, the ε-expansion and derivation of 731 turbulence models, Journal of scientific computing 7(1) (1992), 35-61. 732

[46] G. Mahtabi, and H. Arvanaghi, Experimental and numerical analysis of flow over a 733 rectangular full-width sharp-crested weir, Water Science and Engineering, 11(1) (2018), 75-80. 734

[47] B. Dargahi, Experimental study and 3D numerical simulations for a free-overflow 735 spillway, Journal of Hydraulic Engineering, 132(9) (2006), 899-907. 736

[48] T. M. Salaheldin, J. Imran, M. H. Chaudhry, Numerical modeling of three-dimensional flow 737 field around circular piers, Journal of Hydraulic Engineering, 130(2) (2004), 91-100. 738

[49] P. J. Roache, Perspective: a method for uniform reporting of grid refinement studies, (1994). 739

[50] S. Salehi, and A. H. Azimi, Effects of spoiler and piggyback on local scour under single and 740 twin submerged pipes, Ocean Engineering, 261(2022), 112137.