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Evaluating the Effect of Anti-Vortex Plates on Discharge Coefficient in Short Throat Shaft Spillway

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Abstract

Knowing more about the flow behavior of short-stepped shaft spillways helps to use this structure better and more efficiently. Moreover, using a vortex breaker greatly affects passing flow through Shaft Spillway. For use more efficiently, the risk of the flow of water on the crest decreases to less than fluid vapor. The water head on the crest, called cavitation, should be prevented as long as possible. This research has tried to experimentally study different behaviors of stepped chambers and different vortex breaker shapes on spillway flow. From the viewpoint of the effects of flow regime changes on spillways, changes according to the vortex breaker shapes, and the change of type of flow range will be studied effectively. Finally, the best relationship between the water head on the crest and the discharge coefficient was determined. One of the most important issues on the hydraulic coefficient of the spillway is related to the relationship between the water head on the crest and the hydraulic coefficient of this special hydraulic structure. In other words, when flow changes and moves upward till full pipe condition, knowing about the empirical coefficient of the spillway is very useful to predict hydraulic behavior in different situations.

1. Introduction

The step spillways can significantly decrease the energy loss resulting from the chute and eliminate the need to establish of energy loss system in the structure downstream or decrease it significantly (Rajaratnam et al., 1997). Water flow on a stepped or unsmooth surface in earth dam spillways is completely turbulent and makes small bubbles (Jain, 1987).

Such flow may depreciate a major part of its energy. Therefore, the more the lost energy the less the risk of cavitations due to intense fall of velocity (Maynord, 1985). In this study, the flow capacity is measured in morning spillways regarding many dimensionless parameters of Froude number, at the top of the spillway surface, the h/b ratio for each step and number of steps for two different types of spillways, and finally, Cd (Emptying Coefficient of Shaft Spillway) against Submersible ratio (H/Rs) for different vortex breaker and different arrangement were studied. For determination of the best condition of flow, using different guide pier and its arrangement, Cd against h/rs are Calculated and plotted theoretically. Eventually, some factors that influence on

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emptying Coefficient are present in designing (Reclamation, 1987).

The Glory spillway is commonly used to deplete the flow along the flood (Figure 1). This hydraulic structure can switch the free surface flow to fluid flow through the pipeline which is caused by the glory spillway thread by high velocity flow and flow separation. These cases can generate the cavitation bubble through the Glory spillway. The cavitation phenomenon has commonly happened through the flow with high velocity and minus pressure. The Glory spillways included three main parts the vertical shaft, bend pipe, and horizontal shaft. Some studies were focused on the depletion of the water through the vertical structure such as drop structure which consists of dive flow and vortex drop structures due to free and semi-submerged flow (Jain, 1987; Rajaratnam et al., 1997; Vischer and Hager, 1995). Whirling flow is considered a basic problem in designing hydraulic structures with vertical shafts because it can mix the air and water and due to lack of air above the water surface, the minus static pressure can be generated by circulated currents (Shemshi and Kabiri-Samani, 2017).

Some researchers in the literature argue the vortex drop structures and their impacts on the minus pressure at the bottom of the hydraulic structure (Dong et al., 2011; Hager, 1990; Jain, 1984; Quick, 1990). The results of these researches expound that one of the important matters during the design process for hydraulic structure is predicting some countermeasures to control and avoid minus static pressure. Also, through the hydraulic structure with vertical and horizontal shafts, the high values of the stream-wise velocity can increase the threat of cavitation danger risk (Kasra et al., 2022; Wu et al., 2022). The Morning Glory shaft is a type of spiral inlet that including of three main components: an inlet morning glory spillway, a vertical shaft, and an outlet tunnel (Liu et al., 2018). Switching the angle to the mounted spoilers at the intake of the morning glory spillway can increase the values of the coefficient discharge. Meanwhile, these spoilers can control the rotation of the vortexed currents and as a result, the flow separation at the crest of the Morning Glory spillways tends to be negligible status (Chitsazan and Ghafouri, 2022; Haghbin et al., 2022). Figure 2 shows the anti-vortex blades on the crest spillway. Glory spillways are one of the major hydraulic structures in dams, which are appropriately designed to pass the flow properly and effectively. Therefore, for correct and optimal designing, various conditions should be examined to avoid negative pressures at the spillway crest and other parts of the Glory spillways which may cause instability in the spillway structure and damage to the concrete surface of the spillway due to cavitation phenomena (Jafari and Aghamajidi, 2022; Radmanesh et al., 2022). Considerable research has been conducted to determine the effect of the shape of the crest of the Morning Glory on the aeration. Esmaeilizadeh and Mirzavand (2022) indicated that adjusting and mounting the deflector at the crest position of the morning glory spillways can increase the rate. It was deduced that raising the aeration rate at the crest position of the morning glory spillways can reduce the risk of cavitation because of removing the minus static pressure induced through the vertical shaft.

Figure 1. A real view of the Morning Glory spillway

Figure 2. Anti-vortex blades on crest spillway

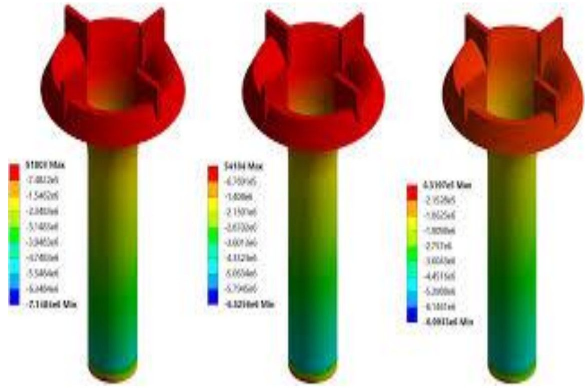


Figure 3. A schematic view of the simulation of Morning Glory spillway in a differential situation

In addition to the shape of the morning Glory spillway, the upstream slope of the intake is an important parameter related to shape to avoid the minus pressure at crest position and downstream position of the intake such as vertical shaft and bend pipe (Figure 3) (Maynord, 1985). Most of the available information includes a wide range of data that has been obtained from the results of physical models done by USACE and USB (Reclamation, 1987). Regarding morning glory spillways, the USBR has done valuable research on the shape of the crest and the passing discharge their results are available in the form of graphs and tables in the Institute's publications. According to available data from USACE and USBR, the computational fluid dynamics (CFD) program, Flow-3D, for different levels of flow for modeling of the morning glory spillway was introduced as an acceptable and reliable application to investigate the parameters of the flow due to different submergence ratio To determine to the hydraulic characteristic of flow in morning glory shaft spillways, many researchers have tried to solve these issues or problems by using some methods such as prototype measurements, experimental and computational methods (Christodoulou et al., 2010; Dong et al., 2011; Fattor and Bacchiega, 2009; Nohani, 2015; Parsaie et al., 2016; Savic et al., 2014; Zhao et al., 2006).

The numerical model was first used by Cassidy (1965) to determine the water surface level and the static pressure on the Glory spillway crest based on a two-dimensional potential flow. Their result illustrated the numerical models are suitable to simulate the flow over the Morning Glory spillways. The results also indicated that the minimum pressure for a given head depends on the boundary conditions. Ikegawa and Washizu (1973) and Betts (1979) used the finite element method linearly to solve the equations governing the flow field. The results obtained were compared with Cassidy results. They found the speed of convergence increased in the numerical analysis. Savage and Johnson (2001) studied the morning glory spillways with ogee crest without the runoff impacts using the Randomized Group Model (RNG). Their comparison shows the discharge and pressure distribution over the spillway can be accurately predicted by employing numerical models. Olsen and Kjellesvig (1998) solved Reynolds averaged Navier-Stokes equations and also analyzed the passing flow over the Glory spillway using standard k - ε equations by considering the two and three-dimensional model. Their results indicated that the numerical model can achieve an appropriate solution for calculating the viscosity, kinetic, and pressure forces. Fiedler (2010) presented the new designs of the Hoover Dam Spillways. He focused on the effective parameters of the Morning Glory spillway demolition such as spillway capacity/dam overtopping issues; spillway conveyance capacity; gate performance in non-flood situations; and performance of spillway linings under high velocity flow to prevent cavitation. Results of this study illustrated that in the Morning Glory spillway, the cavitation danger risk is the initial threat for demolishing the construction do the earth dams. Alfatlawi and Alshaikhli (2015) predicted the values of the discharge coefficient for the stepped morning glory spillways namely circular and quadrate experimentally. Also, the values of the discharge coefficient were predicted equally by using ANN and MNLR approaches. Results showed that the values of the discharge coefficient of the stepped morning glory spillway reduced by increasing the ratio of the H/R (where H is the active water head above the crest and R is the radius of the morning glory spillway). Liu et al. (2002) simulated flow in a newly developed vortex drops shaft spillway using experimental and numerical methods. In this study, hydraulic characteristics such as the flow pattern, air core distribution, annular hydraulic jump position, pressure profiles, and water profiles of the outlet tunnel are obtained and agree well with the measured experimental data. Results displayed that the flow around the inlet is apportioned into a free-flow swirling region near the piers and a submerged-flow region at the piers. Also, analytic calculations for the resultant velocity and water course thickness of the shaft sections were correlated well with the results of a numerical simulation. Cavitation is defined as the formation of a bubble or void within a liquid. If the void is filled primarily with water vapor, the process is further classified as vaporous cavitation (Falvey, 1990). Aghamajidi et al. (2013) studied the hydraulic behavior of smooth surfaces on the performance of the Morning Glory spillway and compared its results with an experimental type stepped-spillway with and without vortex breakers. To study the risk of the cavitation, the Froude number, index of hb/b (where hb is the height of the step and b is the width of the step), the number of steps as well as the distance from the beginning of the spillway has been calculated based on the experimental measurements. Results illustrated that the best type of spillway regarding design and resistance against the risk of cavitation and avoidance from concrete erosion is the stepped spillway with the sixth-stepped spillway. The impacts of dimensions and the number of steps on the flow regime and cavitation in stepped-morning glory spillways were investigated by Bordbar et al. (2010) by using experimental models. Based on the experimental data of the cavitation phenomena, the eleven-stepped spillway with equal height and width was proposed to avoid minus static pressure. Kermani et al. (2013) investigated two important factors influencing the cavitation damage risk including flow velocity and cavitation index on the morning glory spillways in Shahid Abbaspour dam spillway in Iran. Results illustrated that based on these factors, the major damage occurs at the end of chute areas. Also, the cavitation index factor provides better predictions for the cavitation damage levels, than the minus pressure (Asadsangabi et al., 2014) investigated maximum discharge coefficient and cavitation index shaft-spillways using Volume of Fluid (VOF) method and flow turbulence modeled by “k-ε” model. Based on experimental results, models were verified and discharge, velocity, pressure, and cavitation index for different inlet shapes were computed. The results showed that the VOF approach can provide the appropriate results for solving the problems related to the cavitation phenomena (Parsaie et al., 2016). Figure 4indicateds the piping phenomenon on shaft Morning Glory Spillway.

Figure 4. Piping phenomenon on shaft Morning Glory Spillway

Simulated cavitation phenomenon along spillway's flip bucket of the Balaroud dam using Flow-3D. The results of numerical modeling demonstrated that the RNG turbulence model has an appropriate performance for modeling cavitation. Also, the minimum cavitation index in physical modeling was about 0.85, and the minimum cavitation index based on Flow 3D results was about 0.665. It was deduced that due to high values of the water head through the - morning glory spillway, the static pressure achieves positive values and as a result, the cavitation index was obtained than 0.45 which indicated that due to increasing the water depth, the risk of the cavitation is decreased significantly. Morning Glory spillway is commonly threatened by the cavitation phenomena induced by the high values of the velocity and low static pressure because of the performance of this hydraulic structure. It is supposed that finding the safe zone and treated zone by cavitation due to the variating of the flow discharge is an important item for avoiding and controlling cavitation. The Present study carried out some experimental tests on the experimental models of the Morning glory spillway and validated a numerical model based on the experimental information. It is predicted that the different components of the Morning Glory spillway such as the intake of the spillway, vertical shaft, bend pipe, and horizontal shaft were faced with cavitation due to achieving the requirements of the cavitation. Proposing a suitable shape for the components of the Morning Glory Spillway could reduce the statistic of the citation to zero. So, the cavitation number of the semi-submerged flow has the worst impact on the generation of the cavitations with different ratios of D/R (D is the vertical and horizontal shaft diameter size and R is the radius of the pipe bend of the morning glory spillway) were explored numerically and some boundaries were proposed to design of the bend pipe of the morning glory spillway with lower cavitation possibility. Salehi et al (2023) tried to study the effect of bend on cavitation number in the morning glory spillway.

2. Material and Methods

2.1. Discharge regulation

The discharge Coefficient is empirically a function of Fluid Mechanic dimensionless parameters. Where the Discharge Coefficient, the fluid water head on the crest enters dimensional analysis calculations, not only do they make the results more complicated but also bring us far from our main objective. Therefore, the parameters effective in the flow regime and energy loss of the step are to be analyzed.

2.2. Dimensional Analysis

Significant and effective parameters may include the velocity of flow on the spillway surface (v), fluid dynamic viscosity (μ), spillway diameter (Ds), the ground gravity acceleration (g), fluid density (ρ), step width(b), the height of each step(h), and number of steps(N), S (number of Vortex Breaker) and (Cd) as Discharge Coefficient, Cv1 is a related parameter of vortex breaker and Cv2 is a parameter of Stepped chamber It is need to add Cv1 and Cv2 are Dimension less functions of Discharge coefficient. The equation which indicates the mentioned parameters is written as below:

$$F(v, \mu, g, \rho, b, h, D_s, N, S, Cd, Cv1, Cv2) = 0 \quad (1)$$

By the Buckingham method, nine variables with three dimensions M, L and T are available. If the number of variables is deducted from the number of dimensions, the number of dimensionless equations would be achieved. In this article, eight dimensionless equations are developed considering the three variables v, ρ, and Ds as repeated variables:

$$\pi_1 = (v, \rho, D_s, g) = \frac{1}{Fr^2} \quad (2)$$

$$\pi_2 = (v, \rho, D_s, \mu) = \frac{\mu}{\rho v D_s} = \frac{1}{Re} \quad (3)$$

$$\pi_3 = (v, \rho, D_s, b) = \frac{b}{D_s} \quad (4)$$

$$\pi_4 = (v, \rho, D_s, b) = \frac{b}{D_s} \quad (5)$$

$$\pi_2 = (v, \rho, D_s, S) = \frac{S}{D_s} \quad (6)$$

$$\pi_2 = (v, \rho, D_s, h) = \frac{h}{D_s} \quad (7)$$

$$\pi_2 = Cd \quad (8)$$

The first and second dimensionless equations are respectively inverses of Froude and Reynolds numbers. Using multiplication or division of the two dimensionless equations a new dimensionless equation can be made; therefore, by division of the third and the 5th dimensionless equations will be as follows:

$$\prod_7 = \prod_4 \div \prod_3 = \frac{h}{D_s} \div \frac{b}{D_s} = \frac{h}{b} \quad (9)$$

$$\prod_8 = N \quad (10)$$

There are 5 dimensionless equations (equations 1, 2, 4, 5 and 6). However, since the flow in spillways is free and the shear stress is very small near the surface, the effect of dynamic viscosity is very little and ignorable (μ≈0). In this case, the dimensionless equation number 2 is deleted and only the first, fifth, and sixth dimensionless equations are used and analyzed. The sixth dimensionless equation indicated the number of steps. Moreover, one Dimensionless Parameter which is a symbol of the vortex and stepped chamber is defined below:

$$\prod_9 = \frac{C_d}{C_{v1} C v_2} \quad (11)$$

2.3. Data

This study has been inspired by the physical model of the San Luis For eBay dam spillway which is located in the central valley of California, America.

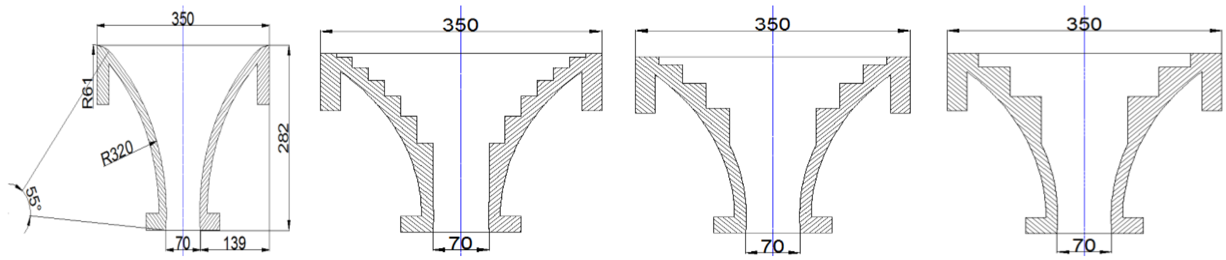
The view of the physical model has been presented in Figures 5. It constituted of a 2000-liter reservoir upstream (including the body of dam, spillway, and water canal), a tunnel for transferring the spillway's water downstream, a 2000-liter reservoir in downstream of the water transfer tunnel and a pump for water suction from the downstream reservoir to the upstream one. In this experimental model, the spillway body including two types of spillways with completely different designs is devised in the upstream reservoir (Figure 6). The surface arc on two sides of the body of all spillways follows the same equation.

Besides, the dimensions of all spillways are the same but the internal surface of each spillway is different from the other. The first type spillway has a smooth surface, and the spillways of the second type respectively have 6 steps, The height of each step is h and the width of each step is b. For the smooth spillway, it has been supposed that the height and width of each step are very small and the same as each other. For the spillways of the second type, the height of each step is continuously changing, and the width of each step is fixed and respectively equal to, two centimeters for each spillway. In the Smooth, six-step spillways, one, two, and more holes are made respectively on a specific section on each step for calculating water height equivalent to the water head on the crest.

In a smooth spillway, the location of holes is considered the same as that of the 8 holes of twelve, six, four, and two-step spillways; therefore, the total of holes in spillways of type one to two is respectively 8, 4, and 9 in this regard. Several holes indicate the Froude number and h/b ratios we require to compare the spillways' surfaces with each other. The number of holes in all spillways should indeed be equal to each other, but due to the long distance of the route, the CNC machine cannot make holes in the ending steps; therefore, only the information related to the available points is compared with each other.

Figure 5. Upper view of the physical model (Dimensions based on millimeters)**.**

To determine the flow regime at the surface of each spillway some holes are made in the spillway body with specific distances from the beginning of each spillway. The role of each hole is to measure the water height equivalent to the fluid water head on the crest at that specific point using a piezometric pipe. (It is to be mentioned that the piezometer pipe is the most accurate fluid water head on the crest measurement instrument). Afterward, an energy equation is established between every two points on the spillway surface according to the Bernoulli principle regardless of fraction loss.



(a) Physical model of smooth spillway

(b) Physical model of the six-step spillway

(c) Physical model of stepped shaft spillway

(d) The picture of total smooth and stepped spillway

Figure 6. (a) Physical model of smooth spillway, (b) Physical model of the six-step spillway, and c) Physical model of other stepped shaft (dimensions of all spillways are based on millimeters), and **(d)** the picture of total smooth and stepped spillway.

Supposing that the flow velocity on the first step is equal to the velocity of the flow entering the spillway, the flow velocity can be calculated from step two on having available the difference of height equivalent to the fluid water heads on the crest. If the flow velocity at each point is specified, the Froude number related to that point can be calculated using equation 12. Besides, to measure the velocity and inlet flow discharge for each spillway, a Triangular weir has been used:

$$\frac{v_1^2}{2g}+\frac{p_1}{\gamma}+z_1=\frac{v_2^2}{2g}+\frac{p_2}{\gamma}+z_2+h_l \quad (12)$$

$$Fr=\frac{v^2}{\sqrt{gD}} \quad (13)$$

$$D=4R=\frac{4A}{P}=D_s \quad (14)$$

To calculate the flow rate, one volumetric cube was used different flow rate was validated, and the Height-Discharge formula for Triangular weir was deducted. The water level of the reservoir and head-on spillway was measured accurately. Finally, different parameters s is calculated.

To govern Vortex creation, in Shaft spillways, always vortex breakers (guide pier) are located at the spillway crest, in this situation for studying the effect of different shapes of vortex breakers, 2 different shapes, and 2 different arrangements are used to estimate flow rate for two spillways (smooth and Stepped Spillways). Figure 7 shows the shapes of spillways.

a. Different types of vortex breakers of Shaft spillway **b.** installation manometer on the body of spillway

Figure 7. The vortex breaker and manometer installation of experimental hydraulic structure

3. Results and Discussion

3.1. Hydraulic behavior of Shaft Stepped Spillway

In the design of dams, spillways are always necessary as safety structures for conveying flood flows. Among the Various types of spillways, the Shaft is a rare option, which may be adopted if space is limited and other local Conditions do not allow a more conventional design.

The structure normally consists of three main components, namely. The cup-shaped overflow inlet, the vertical shaft, and a nearly horizontal conduit led to a dissipation structure.

Ideally, the flow over the crest and into the shaft should have a free surface. Then, considering symmetric radial inflow over the circular crest of radius R, the stage–discharge relationship is similar to that of a straight–creased spillway, substituting the circumference of the cycle, 2πR, for the length L. Indeed, according to recent studies), the discharge is given as:

$$Q = Cd2\pi Rh^{1.5}\sqrt{2g} \quad (15)$$

In this section for estimation of Different Emptying Coefficient of Shaft spillway, some experiments were run as below:

Table 2. Information of experiment which has been used in this study

Type of spillway	Different discharge	Type of vortex breaker	Arrangement	Thickness of vortex breaker	Number of Experiments
4	5	6	3	2	720

For the achievement of the wide variety of data, different discharges from Q= 1.13 lit/s to Q= 6 lit/s were used. For the determination of the discharge coefficient, equation (14) is used ideally. As a result, it was revealed that the best graph and optimum Cd for a smooth Spillway is related to utilizing a vortex breaker with 6 numbers as arrangement, and the best vortex breaker is number 3 in Figure 8. Figure 9 to Figure 11 shows these results.

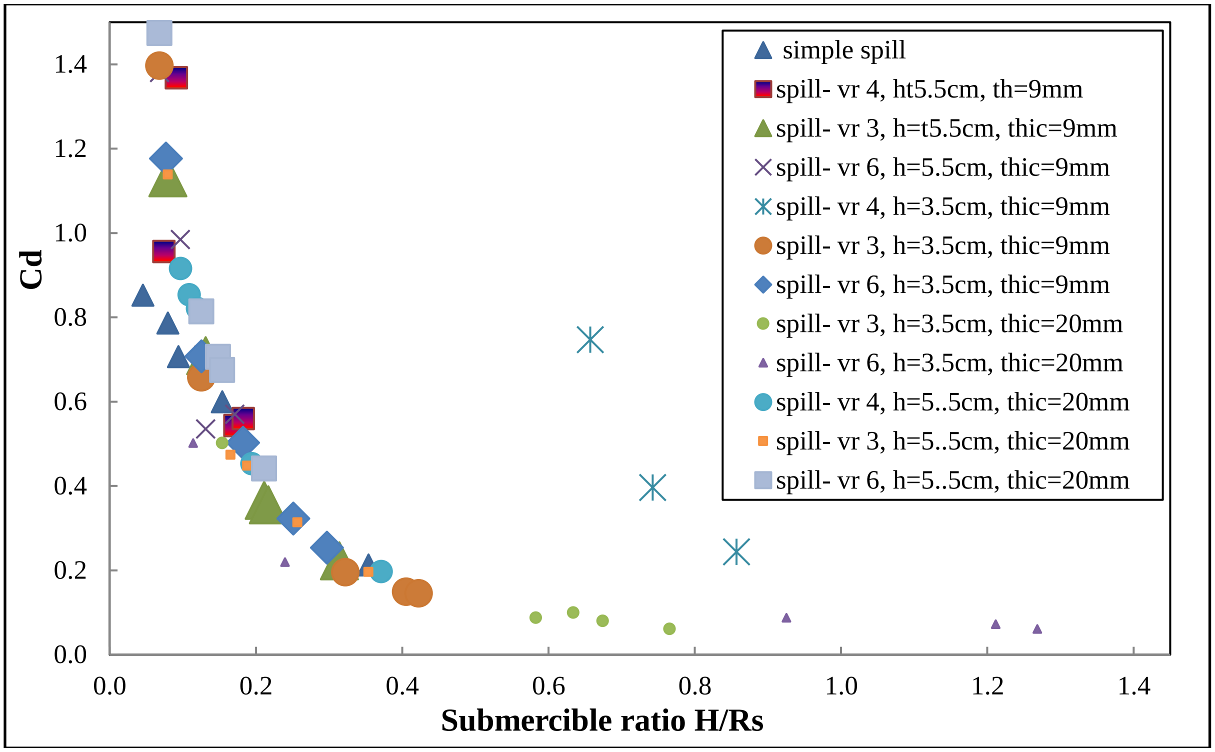


Figure 8. Discharge Cd vs. submersible ratio on smooth spillway

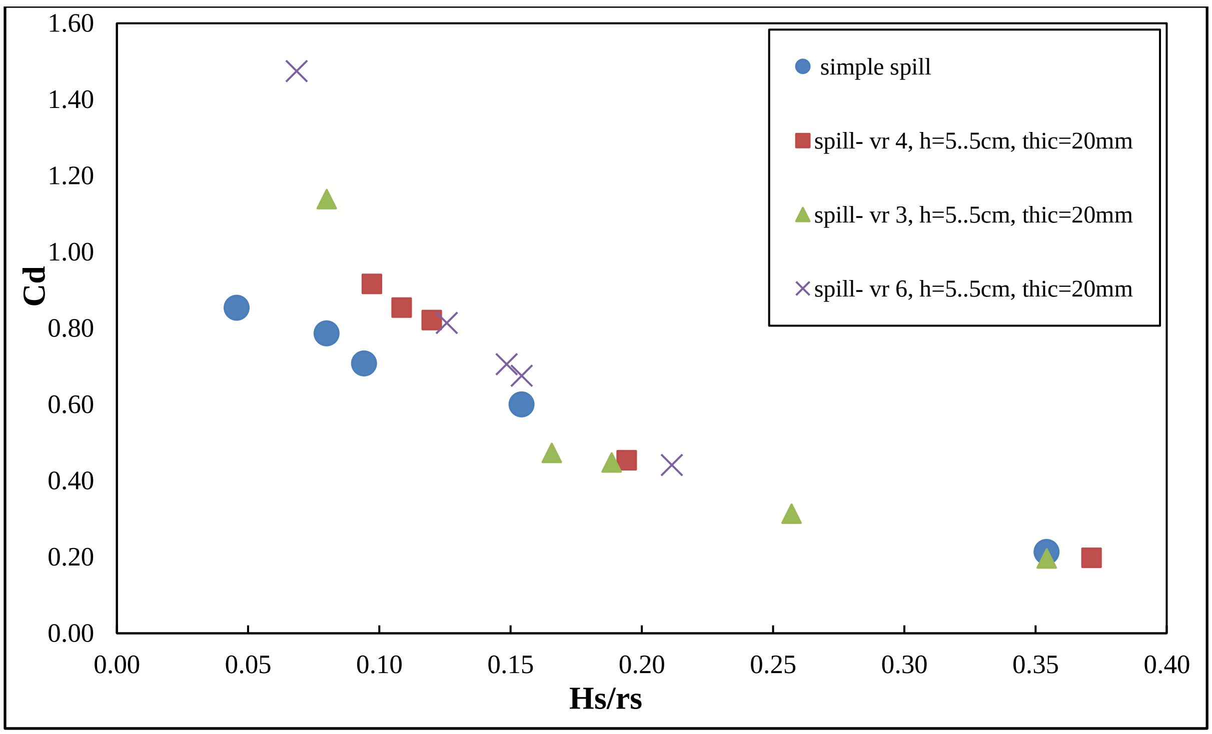


Figure 9. Cd against h/rs (spillway) with low height v. breaker

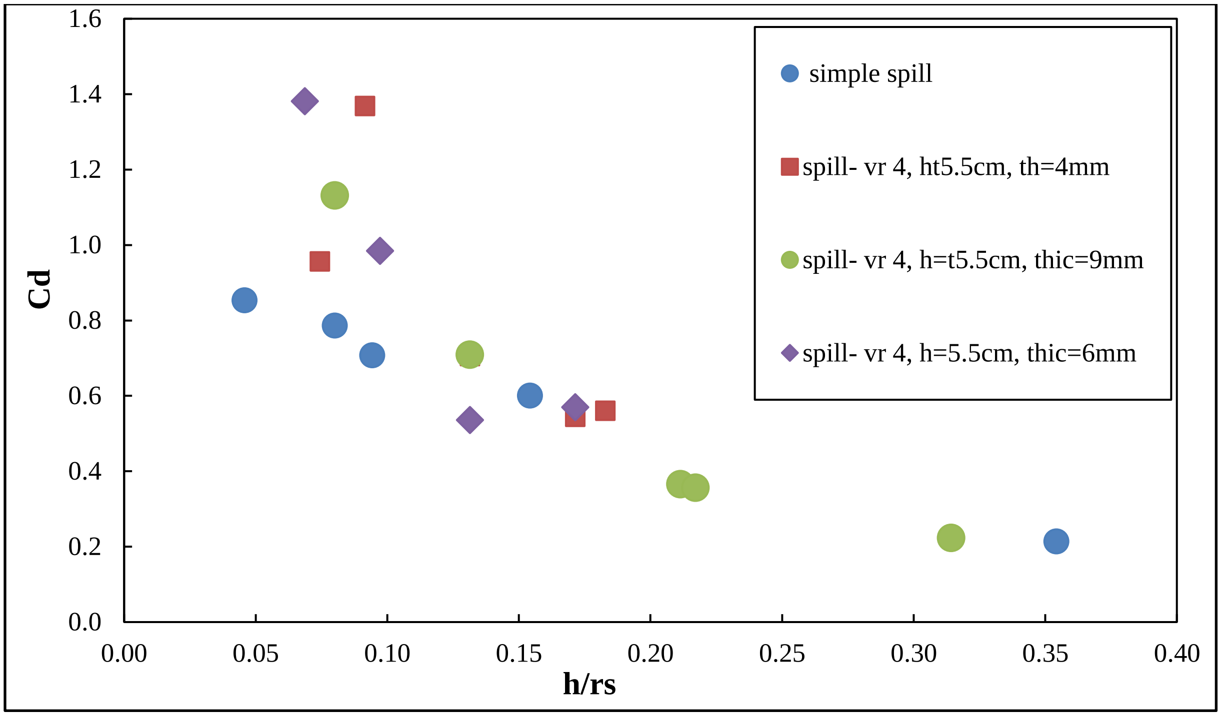


Figure 10. Cd against h/rs with low height v. breaker (for the 4 vortex breakers arrangement on the spillway crest)

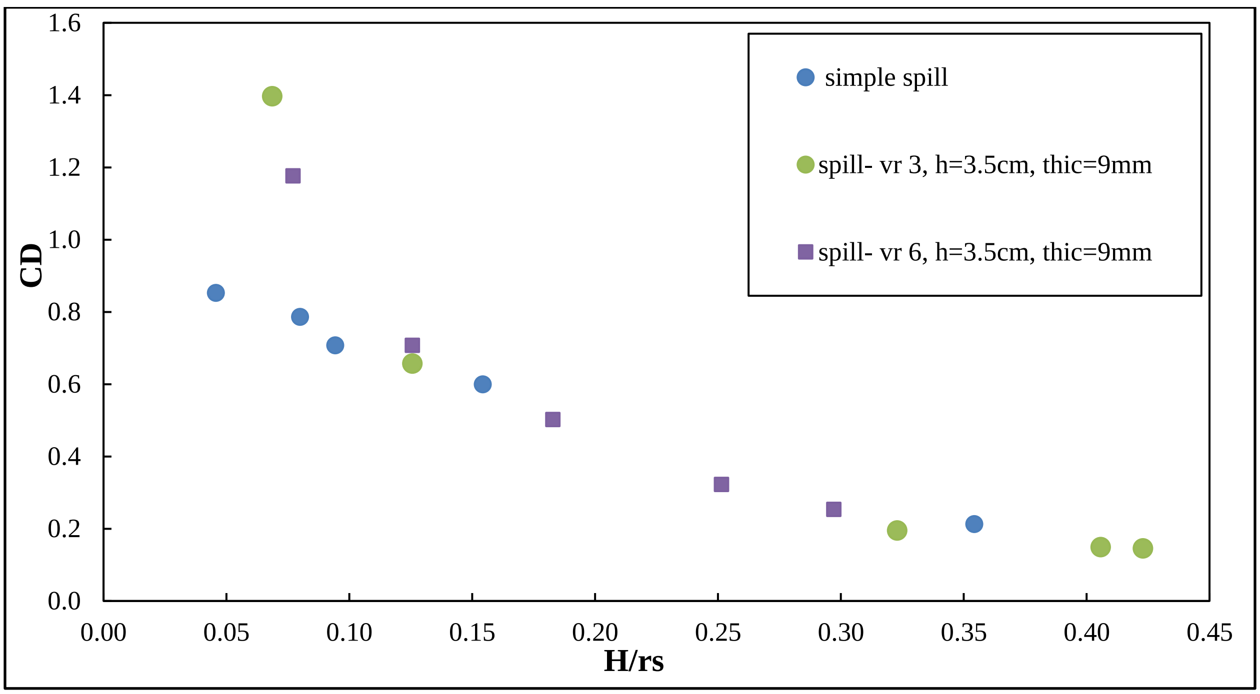


Figure 11. Cd against h/rs with low medium v. breaker.

According to the results from Figure 9 to Figure 11, the best discharge coefficient is related to 6 Vortex breakers as an arrangement and the flow rate increases by more than 15 % on average (at least 13.5% and maximum 23.2% according to the shape of vortex breaker). But it should be added, that the height increase of the vortex breaker has limitations influencing the flow rate increase. On the other hand, when the vortex appears through the spillway body, the Vortex breaking has limitations to controlling the flow rate and while the spillway is completely submerged, the function of vortex controlling is not continued. Moreover, when the thickness of the Vortex breaker is bigger than 0.35Rs, the emptying Coefficient is not effective, especially when a spillway with 4 Vortex breakers is used.

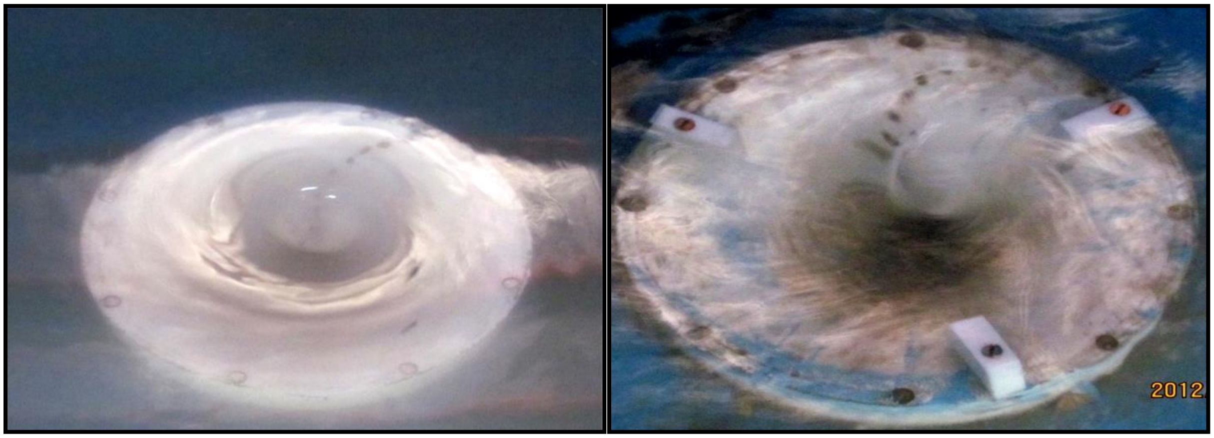


Figure 12. Experiment with three vortex breaker shaft spillways**.**

Due to different discharge and height on the overflow, the results are very different from each other. In other words, the ratio of changes in the discharge coefficient varies from near zero to 1.45 and the absorption ratio also varies from 0.0 to 1.50.

Examining this figure briefly shows that the best diagrams that include good coverage of different heights of water on the spillway are related to the arrangement of 6 breaker on the spillway. In other words, they have a wider dispersion curve and show a relatively lower loss coefficient. In order to further and better investigate the number of changes in the absorption ratio to the discharge coefficient, it has been investigated. It should be noted that in the curve related to the arrangement of 3 and 4 vortex breakers with a height of 3.5 cm and a thickness of 9 mm, they are separated from other data and have a smaller scope of application. However, the best example is the result of the test with the vortex breaker in the Shaft spillway with a smooth channel related to the arrangement of 6 with the vortex breaker of 3.5 cm and 20 mm thickness.it means the discharge flowing more than 1.25 times increased and when the total thickens of vortex breaker on the spillway crest exceeds 25% of the spillway diameter. The hydraulic coefficient suddenly decreases. In other words, it is recommended that the thickness of the vortex breaker is less than 4% of the structure diameter in the arrangement of 6 vortex breakers on the spillway. Stepped Morning Spillway is used the results are completely different, for comparison between two Spillway, all Experiment were Run again, Figure 13 to 15 show the results of runs with Stepped Morning Spillway with 6 Steppes.

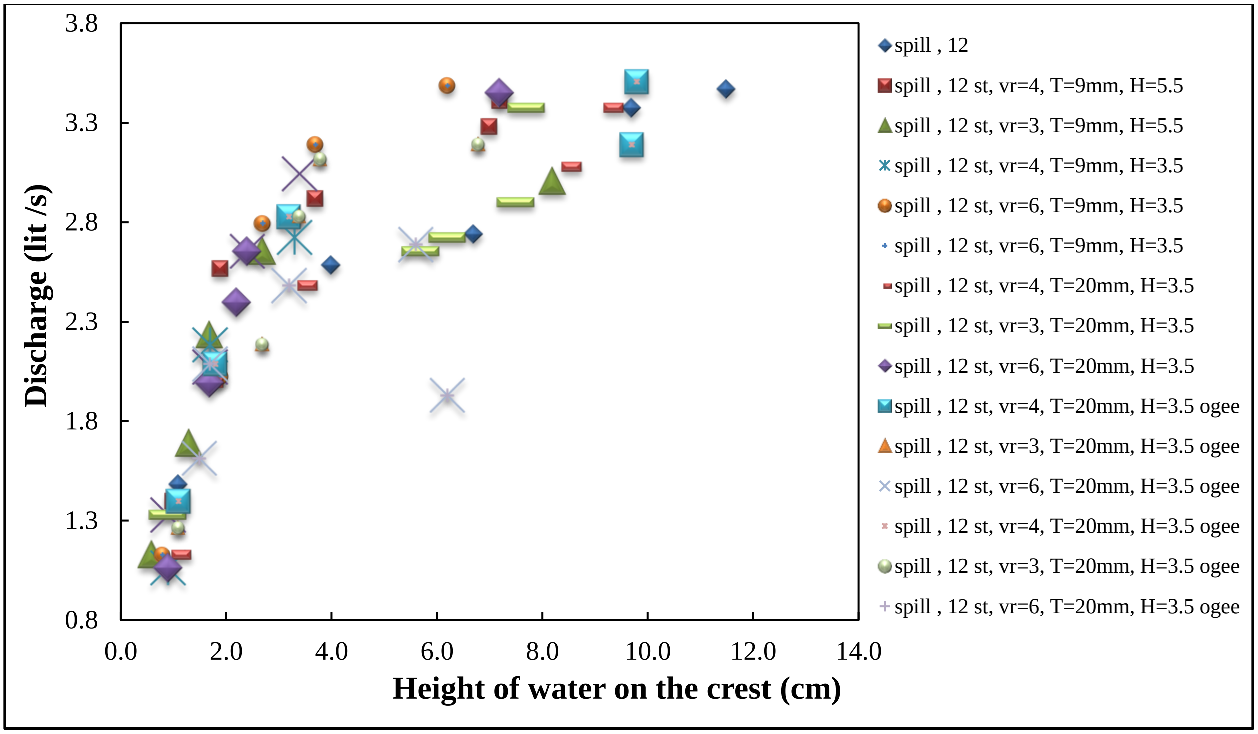


Figure 13. Discharge against Head of water on crest of Spillway (Stepped spillway) with different Vortex Breaker.

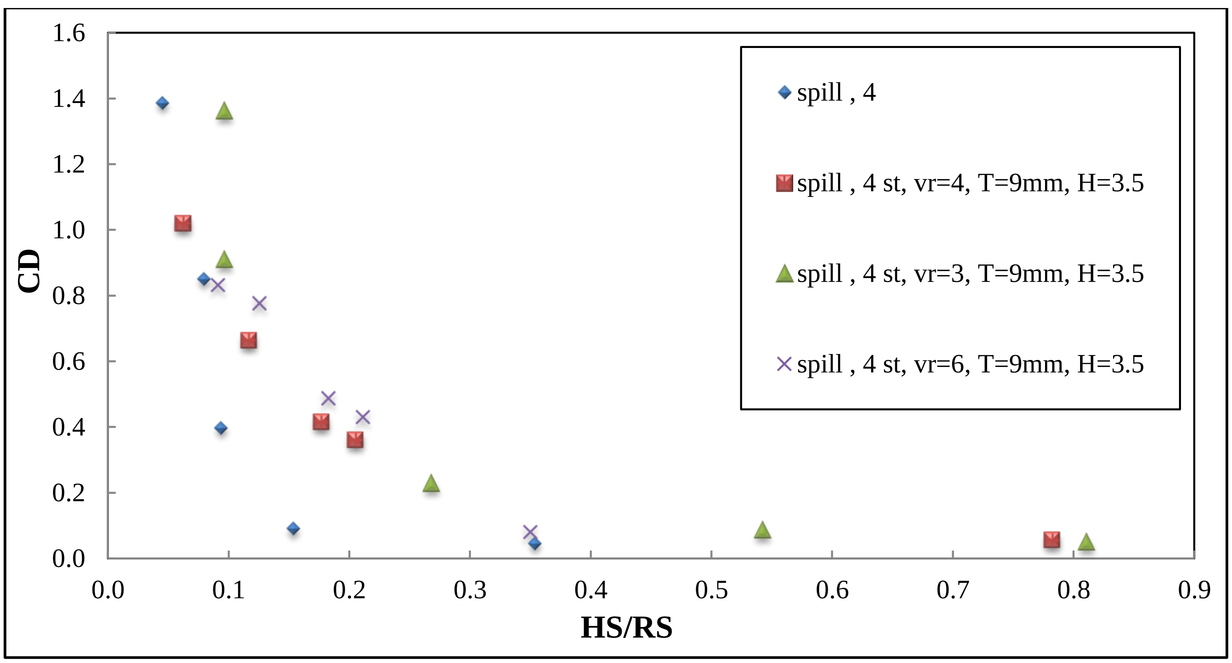


Figure 14. Cd against h/rs (stepped spillway) high height (breaker thickness 20 mm**)**

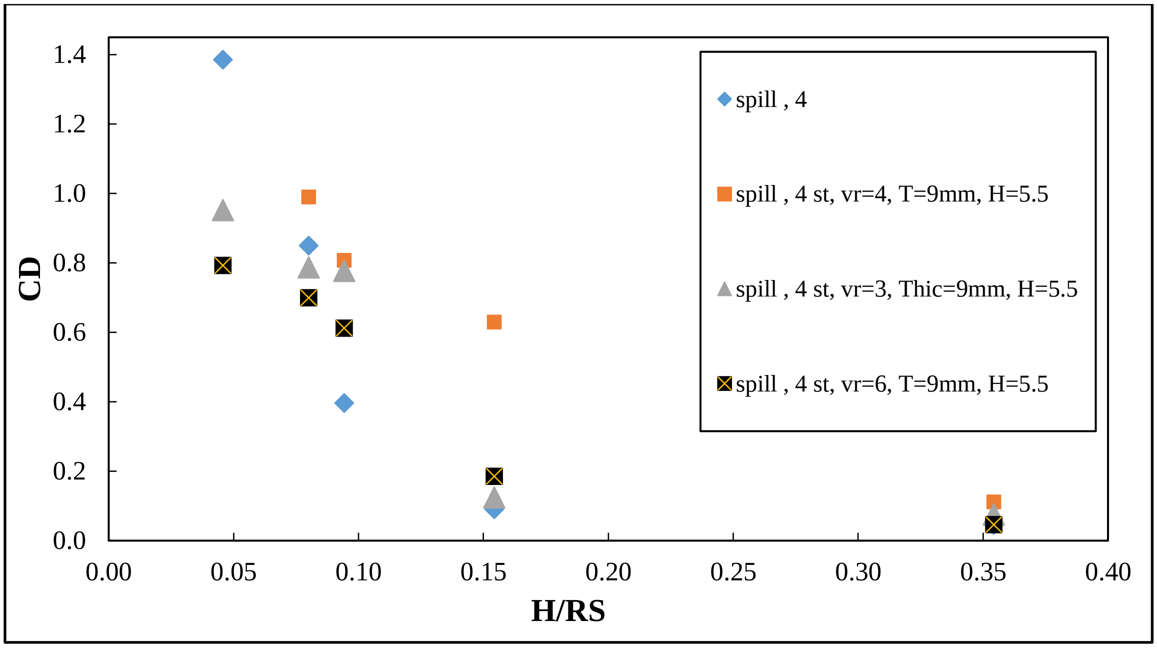


Figure 15. Cd against h/rs (Smooth spillway) with low height (Breaker thickness 9 mm)

As a result, it is revealed that the optimum discharge coefficient is related to 6 Vortex breakers series and the flow rate increases more than 15 % on average for small height stepped spillway. But it should be added, that the Thickness increase of the vortex breaker cannot influence on the flow rate increase. On the other hand, when the vortex appears through the Spillway body, Vortex breaking has limitations in controlling the flow rate while the spillway is completely submerged. This phenomenon is because of the difference in flow regime, which appeared at the Stepped Shaft Spillway. In some cases, using a vortex breaker decreases the flow rate of discharge (Figure 16).

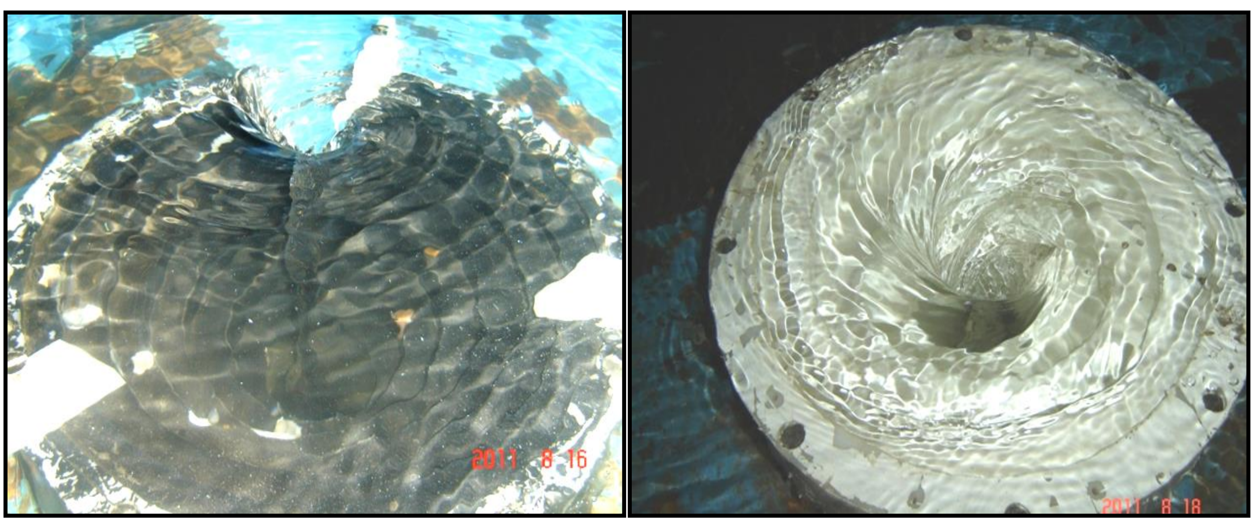


Figure 16. Flow passing through Stepped spillway (stepped spillway).

Table 2. Information of experiment which has been used in this study

Row	type of spillway	type of vortex braker	thickness	number of vortex brakeron crest	number	the length of vortex braker	pecentage of impact on the hydraulic coeficient
1	smooth type	short	20 mm	3.5 cm	6	5.2	increase 17.8
2	smooth type	short	9mm	3.5 cm	4	5.2	decrease 16
3	smooth type	short	9mm	3.5 cm	3	5.2	increase 12.2
4	smooth type	tall	20 mm	5.2	6	7	increase 13.7
5	smooth type	tall	9mm	5.2	3	7	increase 5.8

In the following table the effect of anti-blades vortex on Cd is shown, according this

When some dimension of vortex breaker increase it can be seen that the discharge coefficient would be different (the results domain is very high), but when the number of vortex breaker increased the impact effect will suddenly be decreased.

According to the table 2; the best efficiency for passing flow is related to the 6 arrangement vortex breakers on the spillway crest. For the 4-arrangement vortex breaker, the same result could be seen, more, over, when the thickness of anti-vortex blades increased to exact value, the result suddenly change upside down, in the other words, the hydraulic coefficient decrease to 10%.

- **Stepped chamber effect on hydraulic of morning**

For better understanding, the hydraulic behavior of morning glory spillway tried too briefly as below:

1. The flow of fines that is created at the beginning of the discharge on the spillway. (Effect of vortex breaker is low and friction is high).
2. Fine flow along with step flow with increasing flow rate
3. Creating a state of incomplete absorption (which is seen temporarily).
4. Converting a fine flow to a process that is associated with the creation of a vortex.
5. The control flow of the aperture that is created by the interference of air and the Creation of a turbulent vortex in the middle of the flow.
6. An orifice control flow near the boiling state, which is associated with the shrinking of the vortex in the middle.
7. The complete absorption flow, which is associated with the shrinking of the vortex and the increase of its twist.
8. Creating a hydraulic jump inside the overflow channel
9. Flow with full absorption

The continuation of the flow as a complete absorption. Of course, distinguishing and recognizing each of these flows requires more analysis. In connection with the use of a vortex breaker, the effect of breaking the flow lines and creating an obstacle over it makes this type of flow more complicated. But the use of the vortex breaker creates a special order in the relationship between intake and overflow discharge coefficient. It should be said that the thickness of the vortex breaker does not have a significant effect on the discharge coefficient and sometimes it reduces the flow passing through the duct. In relation to the number of vortex breakers, the results show that the increase of 3 to 6 vortex breakers has little effect on the reduction of the flow loss in the path. Also, due to the stepped channel, increasing the height of the vortex breaker increases turbulence and decreases the flow rate compared to the vortex breaker with a lower height When two spillways compared to each other, it would be found out that, a totally stepped chamber will increase the flow rate, considerably.

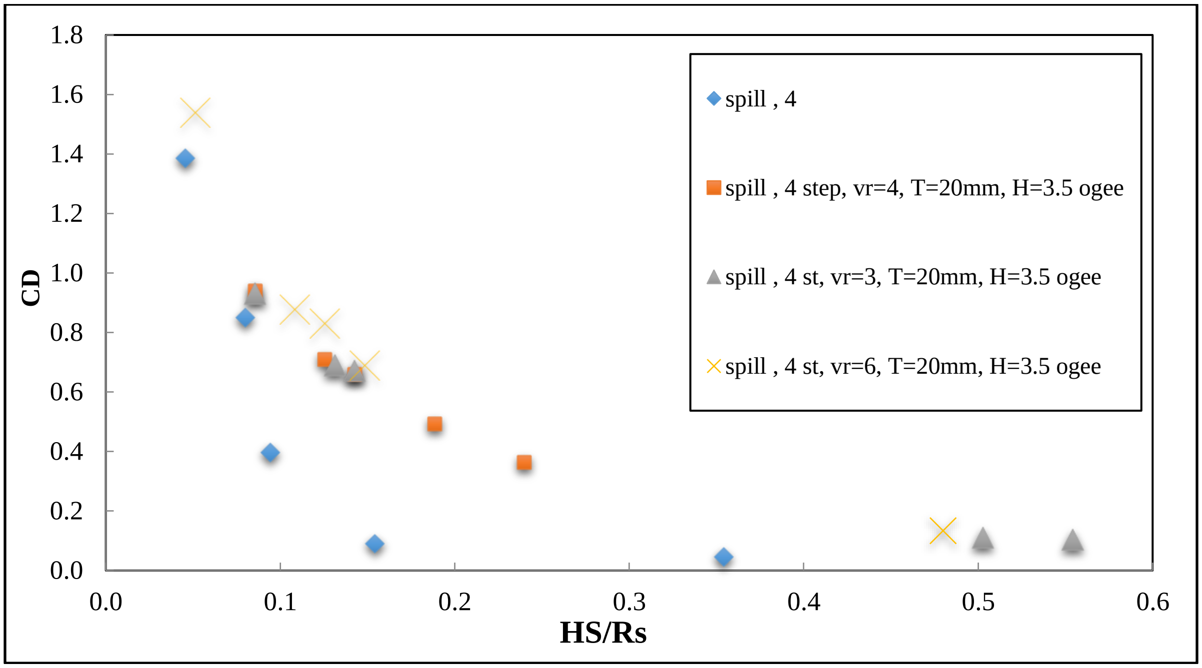


Figure 17. Cd versus h/rs (stepped spillway) and smooth spillway without vortex breaker

According to Figure 18, the stepped Shaft spillway has a better flow rate range and subsequently, it is revealed that the flow rate, in this situation, increases by 12 % on averagely. For a better understanding Effect of a Stepped chamber on flow characteristics, some mathematical equation has been developed for smooth and stepped Shaft spillways by using S.P.S.S software as follows: (The need to add for this section equation (2) has developed). For a smooth spillway, this equation is as below:

$$Cd = 1.725 \times \left(\frac{H}{rs}\right)^{-0.133} \times 0.147\ (Fr)^{-1.38} \qquad (15)$$

For the stepped spillway the equation is as below:

$$Cd = 0.016 \times \left(\frac{H}{rs}\right)^{-1.629} \times 1.949\ (Fr)^{0.364} \qquad (16)$$

These equations show that the effect of a stepped chamber on the Emptying Coefficient is significant and some useful equations can be developed for designing a more efficient spillway.

For studying the effect of different shapes of vortex breakers and different arrangements of guide pier on the crest of the spillway, some different experiments were done. According to these runs, the best efficiency of the discharge coefficient is related to the ogee shape as a vortex breaker with the sixth number on the crest. Table 2 shows the result of different discharge coefficients:

Table 2. Effect of vortex breaker on increasing Discharge Coefficient (Using 6 vortex breakers)

Shape of vortex breaker	Cd	H/R_S	Q(L/s)	Shape of spillway	Efficiency increasing rate
Without vortex breaker	0.41	0.09	2.25	smooth	1
Triangular long	0.81	0.092	2.26	smooth	1.18
Triangular short	0.44	0.172	2.26	smooth	1.14
Triangular middle	0.62	0.141	2.27	stepped	1.08
Ogee shape	0.69	0.12	2.26	stepped	1.24
Rectangular	0.605	0.096	2.26	stepped	1.11

According to Table 2, the best result of utilizing a vortex breaker is related to ogee shape vortex breaker which has a better effect on passing stream lines through the spillway. In other words, minimum eddies will occur when the streamline moves smoothly near the Shaft spillway body, and one boundary line with lower friction will appear subsequently. For better understanding and applicability of Experiments, according to number (10), some coefficients were developed which are presented in Table 3.

Table 3. Effect of vortex breaker on increasing Discharge Coefficient (with Using 6 vortex breakers) and coefficients of steps& vortex breaker

Discharge (lit/s)	H/R_S	Cd	n_v/d	l_v/d	t_v/d	l_c/d	C_{1V}	C_{2v}
2	0.08	0.87	0.00	0.00	0.00	0.00	1.00	1.00
1.98	0.07	1.38	6.00	0.20	0.03	0.00	1.62	1.00
2.03	0.17	0.59	0.00	0.00	0.00	0.00	1.00	0.69
1.97	0.13	0.63	3.00	0.20	0.03	0.06	1.62	0.28
2.05	0.08	0.79	0.00	0.00	0.00	0.09	1.00	0.93
2.04	0.08	0.81	3.00	0.20	0.03	0.09	1.32	0.54
2.05	0.10	0.69	0.00	0.00	0.00	0.11	1.00	0.81
2.06	0.12	0.67	3.00	0.20	0.03	0.11	1.32	0.45

In this table Lc is the number of steps in the spillway barrel, Tv is the thickness of the vortex breaker, L_v is the length of the vortex breaker, d is the structure diameter and H/Rs is a submersible ratio. According to Table 3, the best discharge coefficient is related to a smooth spillway with 6 vortex breakers (Cd= 1.38) and the second better Cd is a stepped spillway, with 12 steps, and 6 vortex breakers. As a result, it is revealed that when the steps chamber is used emptying parameter decreases average by about 30 %, but when a vortex breaker with 6 arrangements and an ogee shape will be utilized, suitable conditions for passing flow will appear. In other words, using a steps chamber has very good efficiency, especially when cavitation risk should be considered. To use these results for using vortex breaker, some equations for calculating Cd based on the Submersible ratio have been developed. These formulas are estimated for twelve steps spillways with different vortex breakers:

Table 4. Design formula for Stepped morning spillway

No	Equations	Descriptions
1	$Cd = 0.073 * \left(\frac{H}{rs}\right)^{-1.218}$	Cd for spillway with 4th Vortex breaker (with ogee shape)
2	$Cd = 0.0578 * \left(\frac{H}{rs}\right)^{-1.125}$	Cd for spillway with 3 Vortex breakers (with ogee shape)
3	$Cd = 0.0278 * \left(\frac{H}{rs}\right)^{-1.678}$	Cd for spillway with 6 Vortex breakers (with ogee shape)
4	$Cd = 0.0321 * \left(\frac{H}{rs}\right)^{-1.3478}$	Cd for spillway with 6 Vortex breakers (with broken angle on top)

3.2. Investigation Water head on the crest on the body of Spillway

One of the most important issues on the hydraulic of the spillway is related to the water head on the crest variation on the crest to the barrel of the spillway. In other words, When, flow changes and move upward till full pipe condition, the water head on the crest will change and fluctuate a lot, while the crest control point transfer to the orifice monitoring condition, some vibration will occur at the down section of Spillway and negative water head on the crest zone appeared and corrosion will damage the inner concrete surface of the spillway. For this reason, gathering information on this point is very important.

According to the study, when flow rises to near unsustainable Submersible zone, the maximum water head on the crest negativity would appear and the crisis for cavitations is this condition. For each spillway with steps chamber and different vortex breakers on the crest, this situation is completely different. It means that different spillway has different condition, but to understand this obligation one recommendation can be present, based on this experiment, while flow will be changed from crest control to orifice zone criticality probably happens. Table 5 illustrates the dangerous zones of different spillways with various conditions.

Table 5. Limitation of cavitations risk versus submersible ratio

No	Spillway type	Vortex breaker arrangement	Minimum H/re ratio for cavitation risk probability	Maximum H/re ratio for cavitation risk probability
1	smooth	6 vortex breakers on crest	More than 0.45	Less than 0.37
2	6 STEPS	6 vortex breakers on crest	More than 0.38	Less than 0.34
3	4 STEPS	6 vortex breakers on crest	More than 0.36	*Less than 0.28*
4	3 STEPS	6 vortex breakers on crest	More than 0.38	*Less than 0.24*

According to Table 5, when the submersible ratio is less than 0.37, then the cavitations Index will be more probably increased. But while the steps chamber is utilized the story is going to be changed and the submersible ration would be changed dramatically.

Besides, the shape of the steps has a great effect on the flow variation regime. Some normal equations could not be achieved and strongly recommend that for each type of step some experiment should be run.

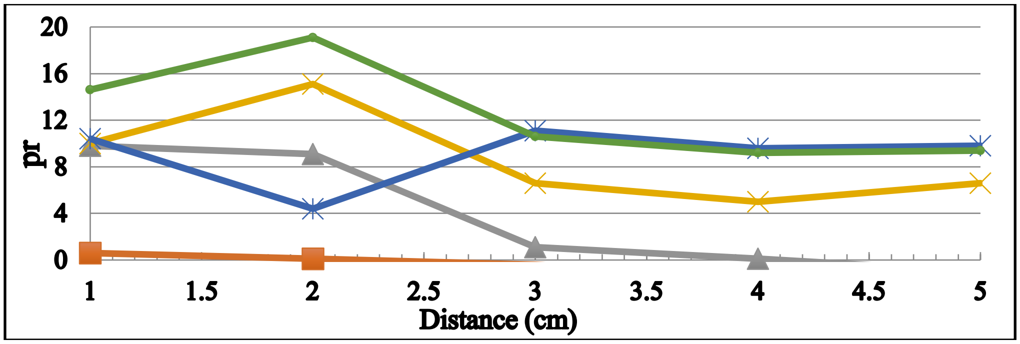


Figure 18. Water head on the crest (on manometer) on the crest of the spillway to the body of the shaft.

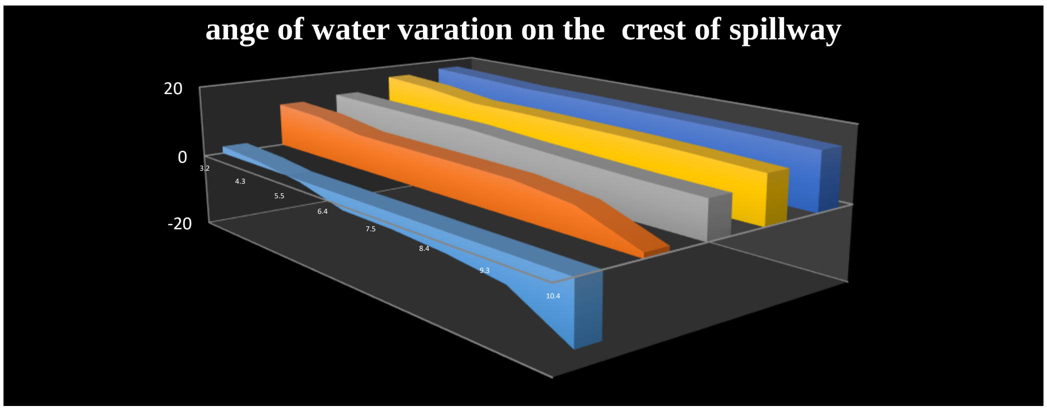


Figure 19. Water head on the crest (on manometer) on the crest of the spillway to the body of the shaft

According to the figure (18) to (19) , because of the variation of discharge and change of water streamline due to hydraulic structure , when the discharge increased slowly the head of water slowly change , but when the hydraulic control change from spillway to orifice the fluctuation would be seen (figure 18 – from point 1 to 2 according to the picture), the changing from point 2, 3 showed the a little variation from orifice control to complete submersible condition ,at this situation ,the variation of stream line will be semi stabilized, but some , creation of small eddies will be formed for very small second , but after a while, this fluctuations will be vanished , and the streamlines will be created supercritical position.

4. Conclusion

Based on the present experimental investigation, the following main conclusions may be drawn:

The maximum risk of flow rate is magnitude at 1/3 downside of shaft, Magnitude velocity is occurred at the end steps of the stepped chamber, and also will take place at ¼ of the stepped Shaft spillway.

According to simulation, the height and width of each step on the stepped chamber has a great effect on the floe regime, especially when the flow regime changes from nape to skimming flow. A morning-glory spillway should be placed as far as possible from reservoir boundaries to ensure radial flow. Over the crest. Then, the discharge calculation is straightforward, with negligible influence of the presence of Piers. Boundary proximity may induce vortex flow and significantly reduce the capacity of the spillway. Therefore, if Vortex development is anticipated, a larger structure (inlet/ shaft/ outlet conduit) would be needed, implying Higher construction costs.

Using a Stepped Shaft spillway has an effect on the flow rate and in some cases, may cause a flow rate increase while using a stepped chamber, the cavitation risk should be considered. According to the runs, although, the stepped chamber on the spillway decreases the flow rate, and also stepped chamber reduces cavitations risk, using a vortex breaker with an ogee shape increases the flow rate to 23%.

Data Availability

The data used to support the findings of this study is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that they have no conflicts of interest regarding the publication of this paper.

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