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Simultaneous Study Effect of Guide Pier and Stepped Chamber on Hydraulic Behavior of Morning Glory Spill Way

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Abstract: Morning glory spillways are circle Spillway used generally for emptying unexpected floods on earth and concrete dams. There are different types of morning glory spillway: Stepped and Smooth types, These spillways (Stepped spillways) pass more flow discharges through themselves in comparison to smooth spillways. Therefore, awareness of flow behavior of these Spillways, help using better and more efficiently. Moreover, using vortex breaker has great effect on passing Flow through morning glory Spillway. To using more efficiently, the risk of flow pressure decrease to less than fluid vapor pressure called cavitations should be prevented as far as possible. At this research, it has been tried to study Hydraulic Behavior of Smooth morning Glory Spillway and compare its result with one type stepped spillway with and without Vortex breakers. From the view point of the effects of flow regime changes on spillway, changes of step dimensions and the change of number vortex breaker will Studied Effectively. Therefore, two spillway models (one smooth spillway and one stepped spillways) with 5different Vortex breaker and Three arrangement have been used to assess the Hydraulic Characteristics of flow and cavitations risk. With regard to the inlet discharge to spillway, the parameters of pressure and flow velocity on spillway surface have been measures at several points and after each run, emptying Coefficient (C d) and Submersible ratio(h/Rs) are studied for Hydraulic behavior with Different Type of Vortex breakers and their arrangement. for the cavitations risk in spillways in comparison with the dimensionless parameter of Froude number at different points of the spillway, height to width of the step (h/b), number of steps as well as the distance from the beginning of the spillway have been measured theoretically and in the form of a diagram for two spillway types. As a result, It has concluded that the best type of spillway in regard to design and resistance against cavitations risk and concrete erosion is th Stepped spillway (Sixth -stepped spillway) with regression index over. Besides, The best vortex breakers arrangement is 6 series that increase water flow discharge more than 12%. Finally, some equations have been developed for designing the steps dimensions based upon flow for the second type spillway with using regression analysis.

Key words: Morning Glory Spillway · Vortex breaker · Flow · Arrangement · Stepped Chamber

INTRODUCTION

Designing stepped canals and Spillway goes back to 3500 years ago and the Greek were the first people who designed them. Water flow loses a part of its kinetic energy while passing the steps and as a result, the flow velocity is decreased and aeration is increased in this Type of spillway [1]. Energy loss in stepped spillways is a key factor for minimizing erosion potentiality of the flow in their downstream. The steps can significantly decrease

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the energy loss resulted from chute and eliminate the need to establishment of energy loss system in structure's downstream or decrease it significantly [1]. The flow on stepped spillways occurs in two skimming and nape Regime. In high discharges, we have skimming flow and in low and intermediate discharges nape flow. Water flow on a stepped or unsmooth surface in earth dam spillways is completely turbulent and makes small bubbles and their development [2]. Such flow may depreciate a major part of its energy. Therefore, the more is the lost energy the less is the risk of cavitations due to intense fall of velocity. In this study, the Flow Capacity and the cavitations risk is measured in morning spillways in regard to many dimensionless parameters of Froude number, at top of spillway surface, the h/b ratio for each step and number of steps for two different types of spillway and finally, Cd (Emptying Coefficient of Morning Glory Spillway) against Submersible ratio (H/Rs) for 5 different vortex breaker and 3 different arrangement were studied. For determination the best condition of flow, with using different guide pier and its arrangement, Cd against h/rs are Calculated and plotted theoretically.

Cavitations Risk: The best type of spillway in regard to resistance against cavitations risk and concrete erosion on spillway surface is to be determined. Therefore, where the flow is supercritical (Froude number is greater than one) the cavitations risk is high. It has tried to find out to what distance from the beginning of the spillway would the durance and resistance of sub critical flow (Froude number is smaller than one) continue. Sub critical flow is considered a safe flow due to the fact that the flow velocity is low in this case, and the less is the flow velocity the less would be the cavitations risk. All over the world, only one physical model of stepped morning glory spillway has been examined so far (1945). The tests conducted on this model in England have indicated that the discharge capacity of the modeled stepped morning glory spillway is more than that of lady bower smooth spillway. For cavitations Risk, However, no analysis or study has been performed on cavitations on such spillway model. Also, some small morning glory spillways have had a stepped level at their downstream, but no modeling test has been conducted on them. Falvey [1] offered the cavitation number as the formula below empirically for sloped steps of the chutes with $L_c/H > 5$:

$$\sigma_i = 1.8\left(\frac{L_c}{H}\right)^{-0.7} \qquad (1)$$

In formula 1, Lc and H respectively indicate the horizontal distance and height of the loped step. Its need to be considered that when Cavitations Index is lower than 0.25, the cavitations will happen. Hazzab, Abbasi and Kamanbedast [2, 3] have studied several hydraulic parameters including critical depth and specific energy for stepped spillways and presented equations in this regard. Egemen and Jorge D. [4,5,6] have studied aeration on two types of smooth and stepped spillways and finally concluded that the mixture of water and air transferred in skimming flow regime is more in stepped spillway than in smooth spillway . In another study, Barani *et al.* [7] studied the energy loss on stepped spillway at different slopes and indicated that the spillways with bigger steps and more discharge have more effect on energy loss. Number of stepped spillways of chute type in the world is very high, and many modeling studies have also been conducted on them. One of the most reliable documents presented in this case is Chanson's [4] book entitled "Hydraulic of Stepped Chutes and Spillways". But the present study includes spillways with circle sections called morning glory spillways; therefore, the information related to stepped spillways of chute type has no application in this study in this regard and the said information is not comparable with the information resulted from the present study. The flow process in morning glory spillways is different from chutes due to the following reasons: A) chute spillways have smooth and linear concrete surface. [8-11] have studied Discharge Coefficient and near optimal arch dam shape for the Morning Glory Spillway Using Artificial Neural Network.

Hydraluic Behavior: In order to evaluate hydraulic behavior of Stepped and Smooth morning glory spillway, Discharge, Emptying Coefficient and water pressure, at different point of Spillway Body, were measured. Different (Cd) s of different conditions and different Algorithm are plotted against Submersible Ratio (H/Rs). Finally, all Results were compared to each other and some formula were Developed.

$$Cd = a*\left(\frac{H}{rs}\right)^{b}*c(Fr)^{d} \qquad (2)$$

Dimensional Analysis

Cavitations Risk: Discharge Coefficient and Cavitations parameter is empirically a function of Fluid Mechanic dimensionless parameter. Where Discharge Coefficient, cavitations and fluid pressure enter dimensional analysis calculations, not only they make the results more complicated but also bring far from our main objective.

Therefore, the parameters effective in flow regime and energy loss of the step are to be analyzed. Significant and effective parameters may include the velocity of flow on spillway surface (v), fluid dynamic viscosity (μ), spillway diameter (D_s), the ground gravity acceleration (g), fluid density (ρ), step width (b), height of each step(h) and number of steps(N), S (number of Vortex Breaker) and (Cd) as Discharge Coefficient. The equation which indicates the mentioned parameters is written as below [10-13]:

$$F(v, \mu, g, \rho, b, h, D_s, N, S, Cd) = 0 \tag{3}$$

In accordance with 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 D_s as repeated variable:

$$\Pi_1 = (v, \rho, D_s, g) = \frac{g\upsilon_2}{v^2} = \frac{1}{Fr^2} \tag{4}$$

$$\Pi_2 = (v, \rho, D_s, \mu) = \frac{\mu}{\rho v D_2} = \frac{1}{Re} \tag{5}$$

$$\Pi_3 = (v, \rho, D_s, b) = \frac{b}{D_3} \tag{6}$$

$$\Pi_4 = (v, \rho, D_s, h) = \frac{h}{D_4} \tag{7}$$

$$\Pi_5 = (v, \rho, D_s, S) = \frac{S}{D_5} \tag{8}$$

$$\Pi_6 = Cd \tag{9}$$

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 following:

$$\Pi_7 = \Pi_4 \div \Pi_3 = \frac{n}{D_3} \div \frac{b}{D_3} = \frac{n}{b} \tag{10}$$

$$\Pi_8 = N \tag{11}$$

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 surface, the effect of dynamic viscosity is very little and ignorable ($\mu \approx 0$). 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.

Hydraulic Characteristics: In addition, for studying flow regime at different situation, 6th dimensionless parameter and 3th parameter, are studied and plot against each other. For achieving this purpose, different experiments were run. And one formula was developed effectively.

MATERIALS AND METHODS

This study has been inspired by the physical model of San Luis For eBay dam spillway which is located at the central valley of California, America. This model, the dimensions of which have been presented in Figure (1, 2), is constituted of a 2000-liter reservoir in upstream (including the body of dam, spillway and water canal), a tunnel for transferring the spillway's water to 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 (Figures 3 to 4). The surface arc on two sides of the body of all spillways follows a same equation.

Besides, 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-step and. 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 is very small and same to each other. For the spillways of the second type, the height of each step is continuously changing and 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 pressure.

In smooth spillway, location of holes is considered the same as that of the 4 holes of Six -step spillway; therefore, the sum total of holes in spillways of type one to two is respectively 8, 4 and 9. In this regard. Number of holes indicates the number of Froude number and h/b ratios we require in order to be able to compare the spillways' surfaces with each other. It is true that the number of holes of all of the spillways should be equal to each other, but due to long distance of the route,

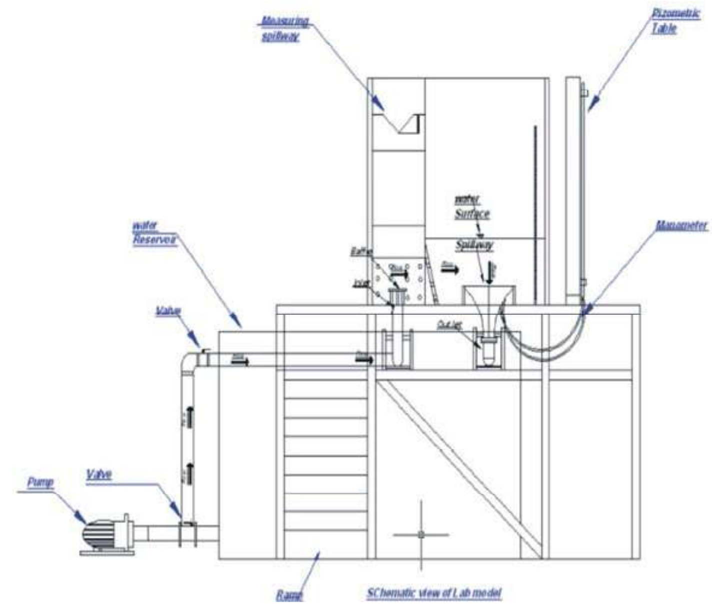

Fig. 1: Cross section of the physical model (dimensions based on millimeter)

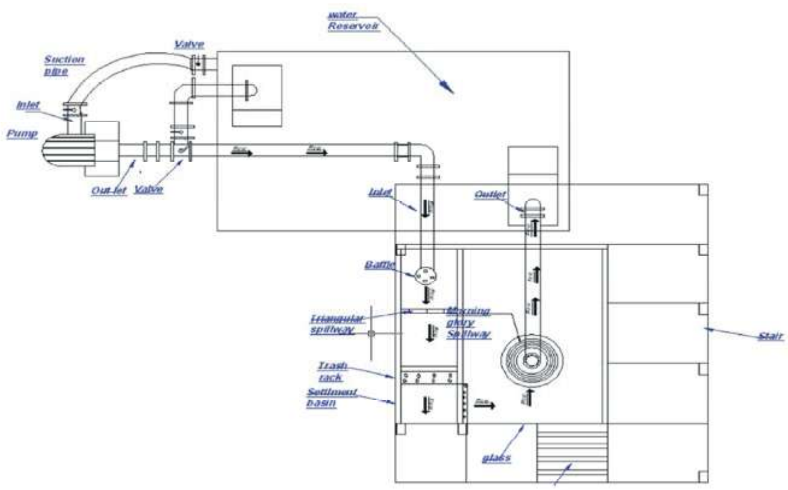

Fig. 2: Upper view of the physical model (Dimensions based on millimeter)

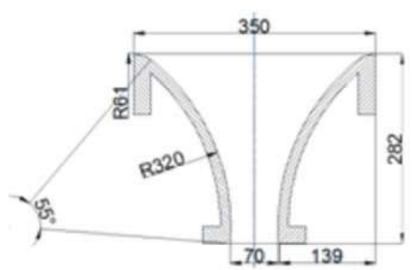

Fig. 3: Physical model of smooth spillway

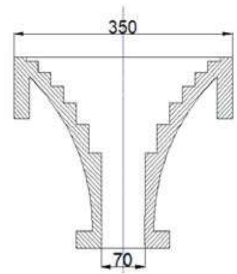

Fig. 4: Physical model of six-step spillway

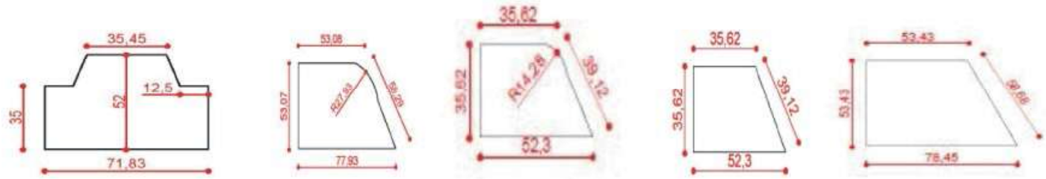

Fig. 5: Different types of vortex breaker of morning glory spillway

the CNC machine cannot make holes in the ending steps; therefore, only the information related to the available points are compared with each other at this Research.

To determine the flow regime (Froude number) at 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 fluid pressure at that specific point using Piezometeric pipe. (It is to be mentioned that Piezometer pipe is the most accurate fluid pressure measurement instrument). Afterwards, energy equation is established between every two points on spillway surface according to Bernoulli principle regardless of fraction loss (equation 11).

Dimensions of All Spillways Are Based on Millimeter: 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 fluid pressure. If the flow velocity at each point is specified, the Froude number related to that point can be calculated using formula 12. Besides, to measure the velocity and inlet flow discharge for each spillway, Triangular spillway has been used

$$\frac{v_1^2}{2g}+\frac{p_1}{\gamma}+z_1=\frac{v_2^2}{2g}+\frac{p_2}{\gamma}+z_2+h_1 \qquad (12)$$

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

$$D=4R=\frac{4A}{P}=D_s=\text{Spillway bigger diameter} \qquad (14)$$

In order to calculate flow rate, one volumetric cube is used and different flow rate was validate and Height – Discharge formula for Triangular spillway was deducted. Water level of Reservoir and head on spillway was measured accurately. Finally different parameter s is calculated.

To govern Vortex creation, in morning glory spillways, always vortex breakers (guide pier) are located at spillway crest, in this situation for studying effect of different shape of vortex breaker, 5 different shape and 3 different arrangement are used to estimate flow rate for two spillways (smooth and Stepped Spillways). The figure (5) shows shapes of spillways.

DISCUSSION AND CONCLUSION

Cavitations Risk: Tables 1 represent the experimental results of two physical models of morning glory spillways. At this table, spillway type (ST), step number (S.N), distance from the beginning of the spillway in meter (D), the fixed value of step height/step width (h/b), Froude number (FR) and supercritical regime of flow (SC) are respectively given from left to right for many types of discharge 2.30 L/second. According to the information relate to flow velocity gained from the physical models, the limitations of regime of flow in discharges $Q_1 = 2.30$,. on each step is specified base on Froude number bigger or smaller than one for all two types of spillway. If the Froude number is smaller than one, the flow is sub critical and if it is bigger than one, the flow is supercritical. Due to significance of the flow regime changes from sub critical to supercritical in dams spillways, the flow regime changes on the considered step of all spillways in all discharges are according to the data given in Tables 1 to 2.

Discussion on Smooth Spillway: in such a spillway, the flow in low and intermediate discharges is sub critical and has nape regime to the 8th step and from the ninth

Table 1: Information on location of flow regime changes on spillways $(Q_1=\frac{2.3lit}{3})$

	Q_1 = 2.3lit/s				
ST	S.N	D	h/b	FR	ROF
1	9	0.35	1	1.41	SC
2	9	0.35	4.25	1.29	SC

Table 2: Information of experiment which has be done

NO	Type of spillway	Different discharge	Type of vortex breaker	Arrangement	Thickness of vortex breaker	Number of Experiments
1	2	5	5	3	2	300

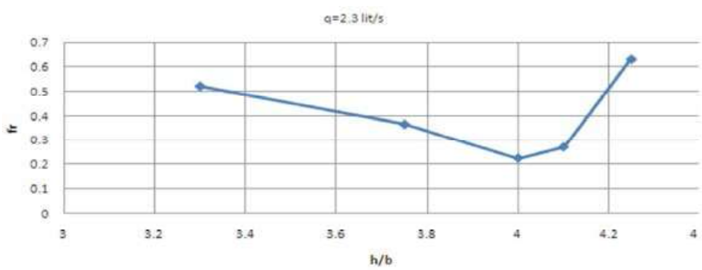

Fig. 6: effect of step on flow regime in six-step spillway (Q=2.3lit/s)

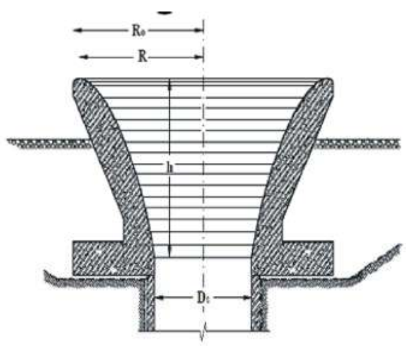

Fig. 7: Typical configuration of a morning glory spillway inle

point on, the flow regime is smooth and supercritical in a 0.08 meter (8 centimeters) distance from the beginning of the spillway. Observations indicate that the cavitation risk does not threaten the spillway until the 8th point and the spillway is exposed to cavitation risk from the ninth point on.

Due to the fact that roughness of smooth spillways is very little, the values of h and b are very small and considered to be almost equal to each other. For the same purpose, their ratio for the points on which the flow is supercritical. When this process was done for stepped morning glory spillway, the result shows that, the Froude number was below than for all steps, so it was deducted that Cavitations risk is not expose until last step. In the other words, when flow flows through spillway, at 1/4 height of down section of spillways, cavitations should be more considered.

Hydraulic Behavior of Morning Glory Stepped Spillway:
4-2-1 Experiment Run: In the design of dams, spillways are always necessary as safety structures for conveying flood flows. Among the Various types of spillways, the morning glory 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 leading to a dissipation structure. A Typical configuration of the inlet is shown in Figure 7.

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 – crested spillway, substituting the circumference of the cycle, 2ðR, for the length L. Indeed, according to Vischer and Hager (1998), the discharge is given as:

$$Q = C_d 2\pi R \sqrt{2g} H^{3/2} \qquad (15)$$

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

For creation wide variety of information different discharge from Q= 1.13 lit/s to Q= 4.5 3 lit/s were used. And for determination of Discharge Coefficient, equation (14) is used idea ally. As a result, It was revealed that best graph and optimum Cd for smooth Spillway is related to utilize vortex breaker with 6 number as arrangement and the best vortex breaker is number 3 in Figure (5). Figure (8) to Figure (11) shows these results.

According to figure (9) t o figure (11) the best Discharge Coefficient is related to 6 Vortex breakers as Arrangement and the flow rate increase more than 15% averagely. But it should be add, that height increase of vortex breaker has limitation to influence on flow rate increase. In the other hand, when vortex will appeared through Spillway body, Vortex breaking has limitation to

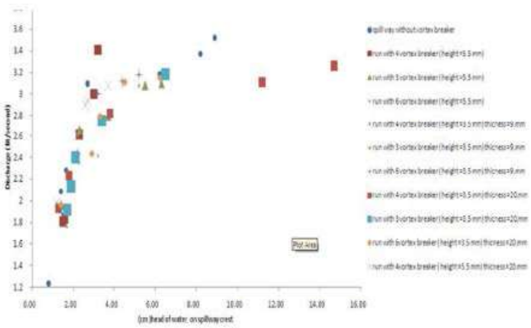

Fig. 8: Discharge against Head of water on crest of Spillway (Smooth spillway) with different Vortex Breaker

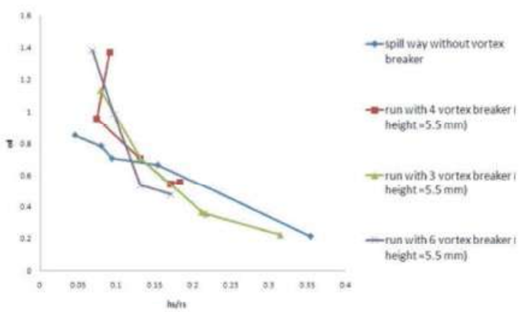

Fig. 9: Cd against h/rs (Smooth spillway) with low height v. breaker

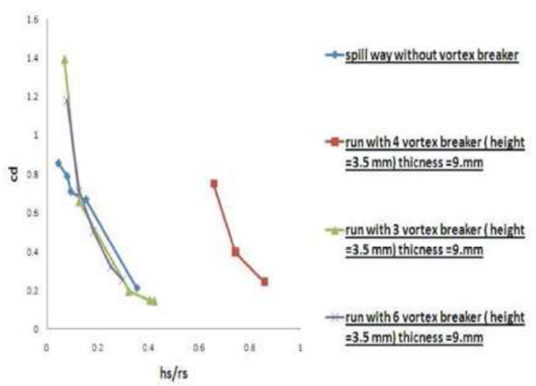

Fig. 10: cd against h/rs (Smooth spillway) with low height v. breaker

control flow rate and while spill way is completely submerged, the function of vortex controlling is not continued. Moreover, when the thickness of Vortex breaker is bigger than 0.2Rs, the emptying Coefficient is not effective, especially when spillway with 4 Vortex breaker will used.

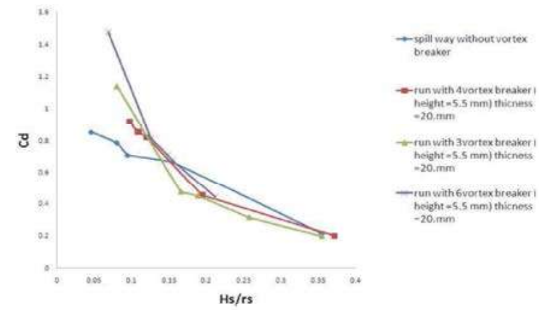

Fig. 11: Cd against h/rs (Smooth spillway) with low medium v. breaker

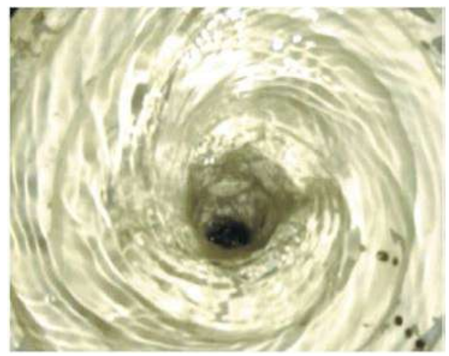

Fig. 12: Experiment with three vortex breaker on smooth morning spillway

When Stepped Morning Spillway are used the results are completely different, For comparison between two Spillway, all Experiment were Run again, Figure (13) to (16) show the results of runs with Stepped morning Spillway with 6 Steppes.

As a result, it is revealed that the optimum Discharge Coefficient is related to 6 Vortex breakers series and the flow rate increase more than 13% averagely. But it should be add, that Thickness increase of vortex breaker has limitation to influence on flow rate increase. In the other hand, when vortex will appeared through Spillway body, Vortex breaking has limitation to control flow rate and while spill way is completely submerged. This phenomenon is because of difference of flow regime, which appeared at Stepped morning glory Spillway. In some cases, using vortex breaker decrease flow rate of discharge (Figure (15)).

When two of spillway compared to each other, it would be found out that, totally stepped chamber will increase flow rate, considerably.

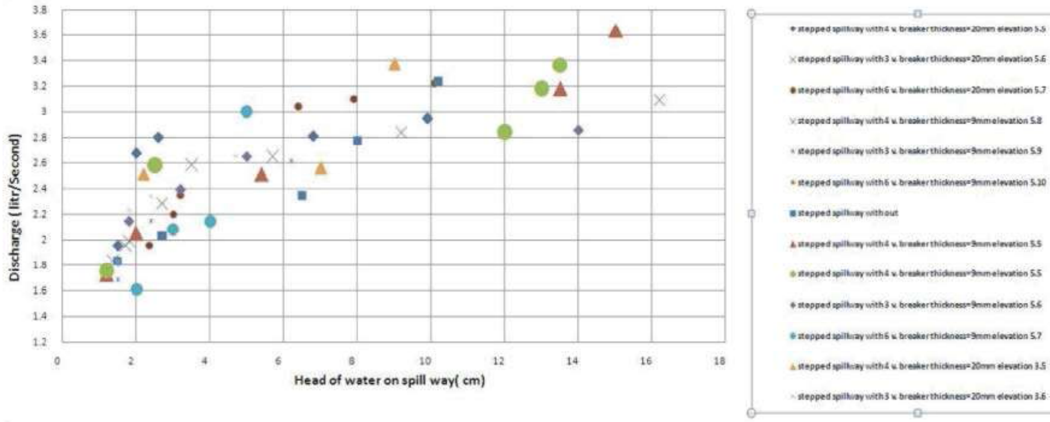

Fig. 13: Discharge against Head of water on crest of Spillway (Stepped spillway) with different Vortex Breaker

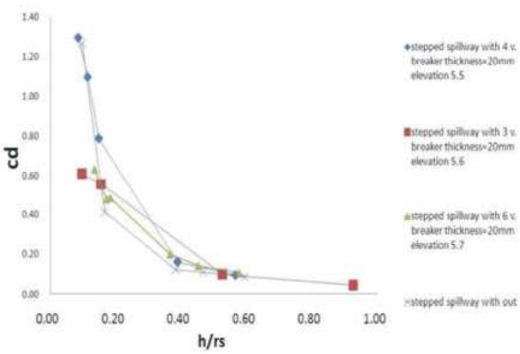

Fig. 14: cd against h/rs (stepped spillway) high height v. breaker thickness 20mm

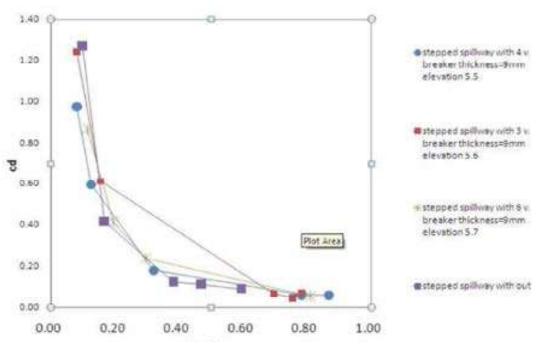

Fig. 15: cd against h/rs (Smooth spillway) with low height v. breaker thickness 9 mm

According to figure (18), the stepped morning glory spillway has better flow rate range and subsequently it is revealed that flow rate, at this situation, increase 12% averagely.

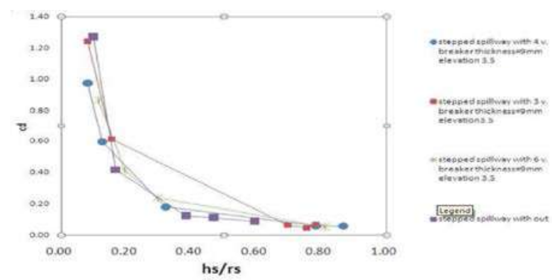

Fig. 16: Cd against h/rs (stepped spillway) with low medium v. breaker

Fig. 17: Flow passing through Stepped spillway

For better understanding Effect of Stepped chamber on flow characteristics, some mathematical equation has been developed for smooth and stepped morning glory spillway by using S.P.S.S software as fallowing: (Its need to add for this section equation (2) has developed). For Smooth spillway this equation is as below:

$$Cd = 1.725 * \left(\frac{H}{\tau_2}\right)^{-0.133} * 0.147(Fr)^{-1.38} \quad (16)$$

For stepped spillway the equation is as below:

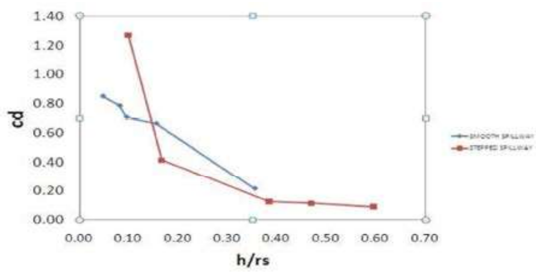

Fig. 18: Cd against h/rs (stepped spillway) and smooth spillway without vortex breaker

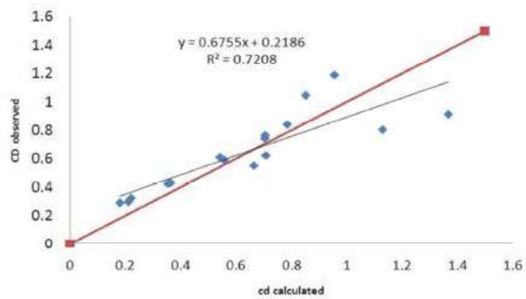

Fig. 19: Calculated cd against observed cd for smooth spillway

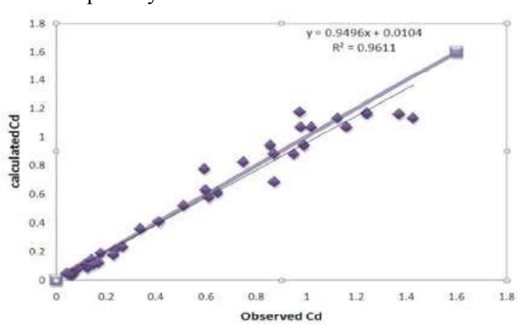

Fig. 20: Calculated cd against observed cd for for 6 stepped spillway

$$Cd = 0.016 * \left(\frac{H}{\tau_2}\right)^{-1.629} * 0.949(Fr)^{0.564} \qquad (17)$$

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

CONCLUSIONS

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

- 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.

Placement of piers on the crest is an efficient way of coping with the negative effects of the vortex. The Significance of piers is evident mainly for high discharges, as they can limit the stage increase to about half the Value observed without piers and also suppress water level oscillations.

In the case of vortex flow, it is not possible to approach the theoretical discharge capacity - or, alternatively, the discharge coefficient – simply by using a large number of piers. Their optimum number is three or six, Beyond which no further improvement can be expected. The orientation of piers (provided they are regularly Spaced) makes no appreciable difference to the flow.

Using Stepped morning glory spillway has effect on flow rate and in some cases, may caused flow rate increase. While using stepped chamber, the cavitations risk should be considered.

Using vortex breaker has great influence on emptying coefficient of stepped morning glory Spillway.

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