Investigation Discharge Coefficient Function of Semi Short Through Shaft Spill Way Considering Stepped Barrel and Vortex Breaker

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Abstract: Semi short through Shaft spillways are circling Spillways used generally for emptying and evacuating unexpected floods on earth and concrete dams. There are two types of Shaft spillways: Stepped and Smooth ones. These spillways) passes more flow discharges through themselves in comparison to smooth spillways theoretically. 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 semi short through Shaft Spillway. For using more efficiently, the risk of flow pressure decreases to less than fluid vapor pressure, called cavitations, should be prevented as far as possible. At this research, it has been tried to study Different behavior of Stepped chamber and different vortex shapes on spillway flow. From the viewpoint of the effects of flow regime changes on spillway, changes of step dimensions and the change of type of discharge will Studied Effectively. Therefore, two spillway models (one smooth spillway and one stepped spillway) with three different vortex breakers and three arrangements have been used to assess the Hydraulic Characteristics of flow. With regard to the inlet discharge to spillway, the parameters of pressure and flow velocity on spillway surface have been measured at several points. As a result, It had concluded that the best type of spillway,with maximum discharge coefficient, is smooth spillway with vortex breaker s ogee shapes with three numbers as arrangement on spillway crest. Finally, Discharge of different condition as function of Steps height, shapes of vortex breaker with higher Efficient arrangement and Submersible ratio are presented for better designing.

Key words: Semi short through Shaft Spillway · Vortex breaker · Flow · Steps · Submersible ratio · Discharge Coefficient

INTRODUCTION

Designing 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 flow in downstream. The step spillways can significantly decrease 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 napped Regime. In high discharges, skimming flow will appeared and in low and intermediate discharges napped flow would occur.

Water flow on a stepped or unsmooth surface in earth dam spillways is completely turbulent and makes small bubbles [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 is measured in morning spillways in regard to many dimensionless parameters of Froude number,at top of spillway surface, the h/b ratio for

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each step and number of steps for two different types of spillway and finally, C_d (Emptying Coefficient of Semi short through Shaft Spillway) against Submersible ratio (H/R_s) for different vortex breaker and 3 different arrangement were studied. For determination the best condition of flow, with using different guide pier and its arrangement, C_d against H/R_s are Calculated and plotted theoretically. Eventually, some factors which are influenced on emptying Coefficient are present for designing.

Discharge Evaluation: Discharge Coefficient and is empirically a function of Fluid Mechanic dimensionless parameters. Where Discharge Coefficient, fluid pressure enters 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 …(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 (C_d) as Discharge Coefficient, Cv1 is related parameter of vortex breaker and Cv2 is 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:

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

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:

$$\Pi_1 = \left(v,\rho,D_s,g\right) = \frac{gD_s}{v^2} = \frac{1}{Fr^2} \qquad (2)$$

$$\Pi_2 = \left(v,\rho,D_s,\mu\right) = \frac{\mu}{?VD_s} = \frac{1}{Re} \qquad (3)$$

$$\Pi_3 = \left(v,\rho,D_s,b\right) = \frac{b}{D_s} \qquad (4)$$

$$\Pi_4 = \left(v,\rho,D_s,h\right) = \frac{s}{D_s} \qquad (5)$$

$$\Pi_5 = \left(v,\rho,D_s,s\right) = \frac{s}{D_s} \qquad (6)$$

$$\Pi_6 = Cd \qquad (7)$$

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:

$$\Pi_7 = \frac{h}{b} \qquad (8)$$

$$\Pi_8 = N \qquad (9)$$

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. Moreover, one Dimensionless Parameter which are symbol of vortex and stepped chamber is define as below:

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, 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
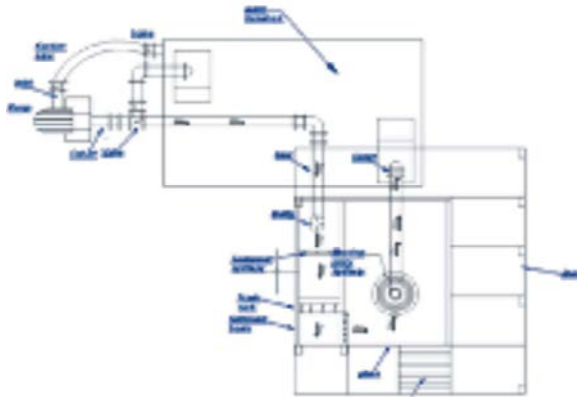
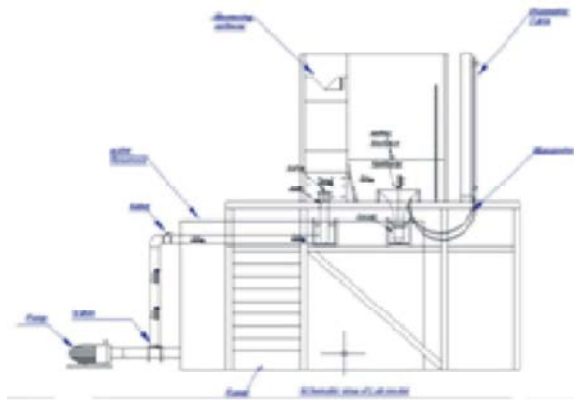Fig. 1: Upper view of the physical model (Dimensions based on millimeter)

Fig. 2: Cross section of the physical model (dimensions based on millimeter)
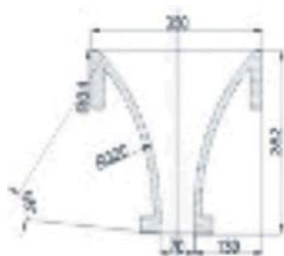

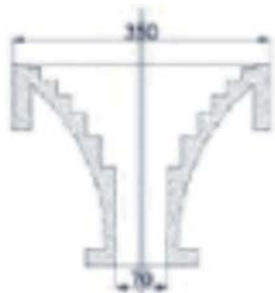
Fig. 3: Physical model of smooth spillway

Fig. 4: Physical model of six-step spillway(Dimensions of all spillways are based on millimeter)
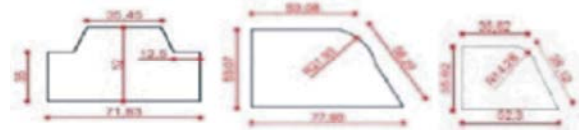

Fig. 5: Different types of vortex breaker of semi short through Shaft spillway

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 8 holes of twelve, six, four and two -step spillways; 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 Froude number and h/b ratios we require in order to compare the spillways' surfaces with each other. It is true that the number of holes in all spillways should be equal to each other, but due to long distance of the route, the CNC machine cannot make holes in the ending steps; therefore, only the information related to the available points are compared with each other.

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 Pizometeric 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.

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 weir has been used:

$$\frac{V_1^2}{2g} + \frac{p_1}{\gamma} + Z_1 \tag{10}$$

$$Fr = \frac{v^2}{\sqrt{gD}} \tag{11}$$

$$D = 4R = \frac{4A}{p} = D_3 = \text{Spillway bigger diameter} \qquad (12)$$

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

To govern Vortex creation, in semi short through Shaft spillways, always vortex breakers (guide pier) are located at spillway crest, in this situation for studying effect of different shape of vortex breaker, 2 different shape and 2 different arrangement are used to estimate flow rate for two spillways (smooth and Stepped Spillways). The figure (4) shows shapes of spillways.

DISCUSSION AND CONCLUSION

(Hydraulic behavior of semi short through 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 semi short through 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 leading 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 – crested spillway, substituting the circumference of the cycle, 2δR, for the length L. Indeed, according to Vischer and Hager (1998), the discharge is given as:

$$Q = c_d \, 2\pi R h^{1.5} \sqrt{2} \qquad (13)$$

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

For creation wide variety of information different discharge from Q= 1.13 lit/s to Q= 6 lit/s were used. And for determination of Discharge Coefficient, equation (14) is used ideally. As a result, It was revealed that best graph

and optimum C_d 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 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.

When Stepped Morning Spillway are used the results are completely different, For comparison between two Spillway, all Experiment were Run again, Figure (13) to (4) 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 semi short through Shaft 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.

According to figure (15), the stepped semi short through Shaft spillway has better flow rate range and subsequently it is revealed that flow rate,at this situation, increase 12 % averagely. For better understanding Effect of Stepped chamber on flow characteristics, some mathematical equation has been developed for smooth and stepped semi short through Shaft 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:

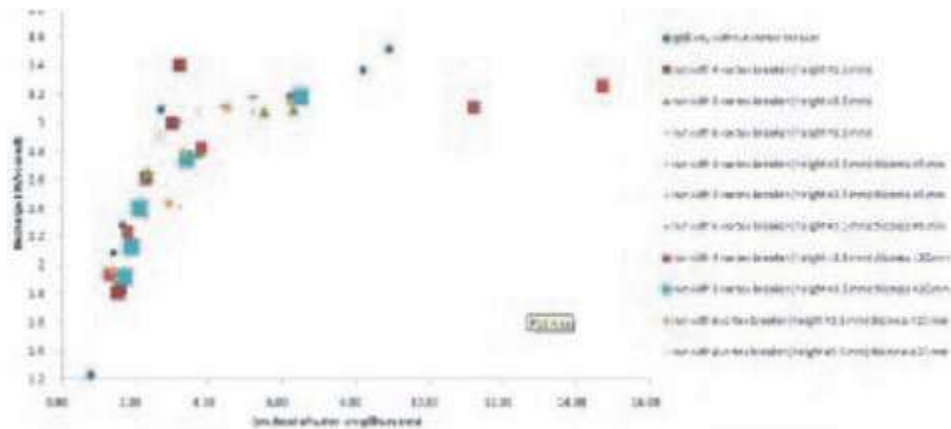$$C_d \, 1.725 * \left(\frac{H}{rs} \right)^{-0.133} * 0.147 (Fr)^{-1.38} \qquad (14)$$

Fig. 6: Discharge against Head of water on crest of Spillway (Smooth spillway) with different Vortex Breaker
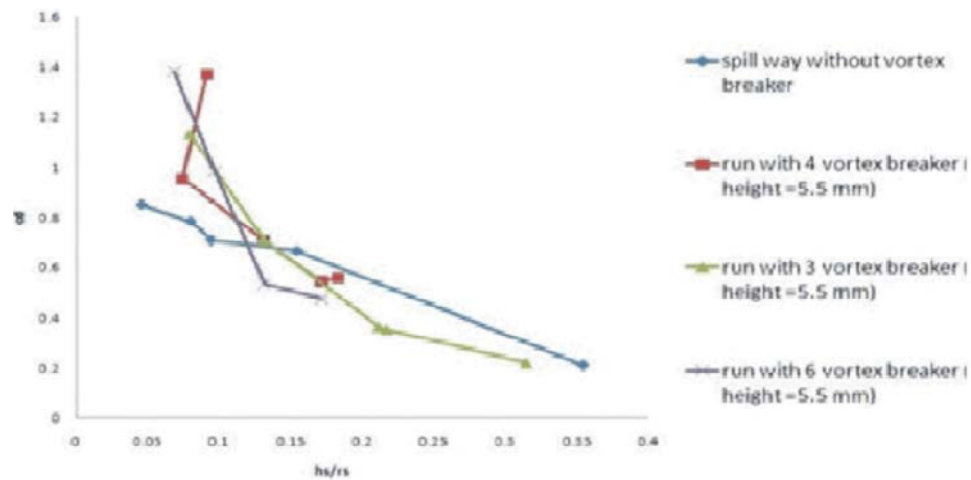

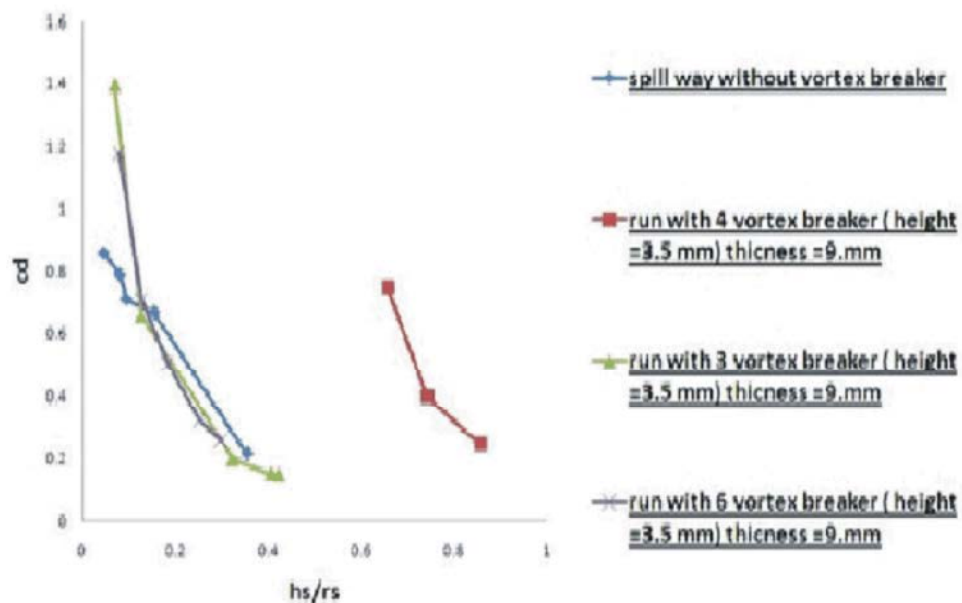Fig. 7: Cd against h/rs (Smooth spillway) with low height vortex. breaker

Fig .8: C_d against H/R$_s$ (Smooth spillway) with low height vortex. breaker
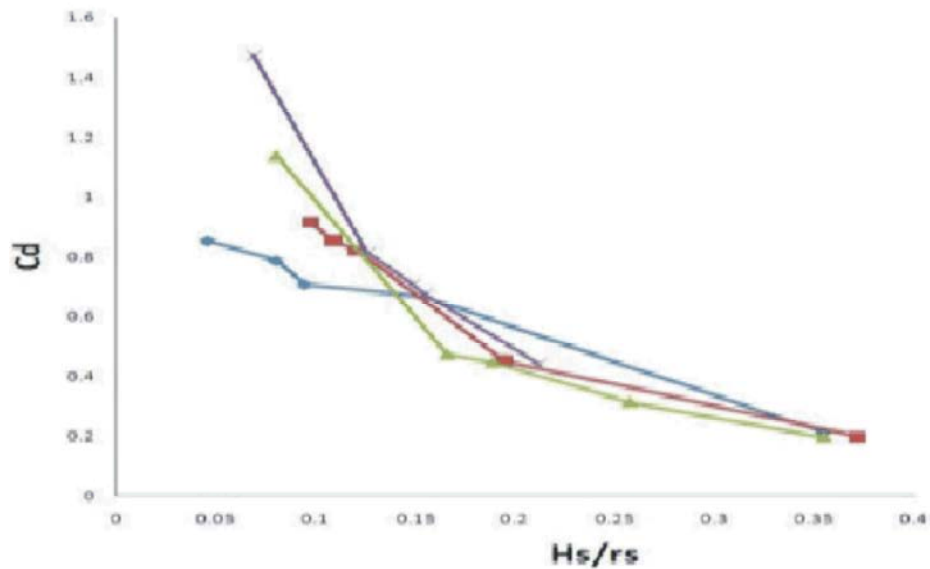
Fig. 9: C_d against H/R_s (Smooth spillway) with low medium vortex. breaker Picture(1). Experiment with three vortex breaker on stepped morning spillway
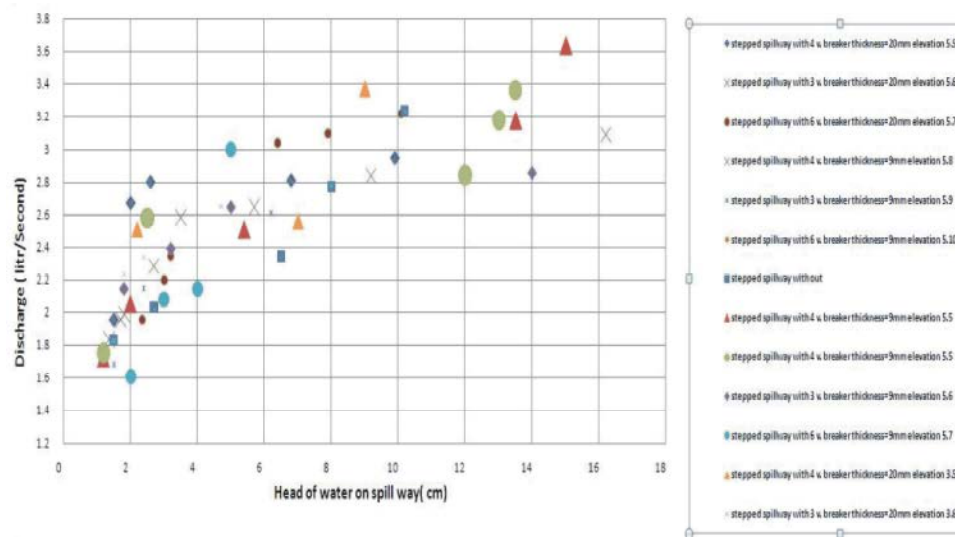

Fig. 10: Discharge against Head of water on crest of Spillway (Stepped spillway) with different Vortex Breaker

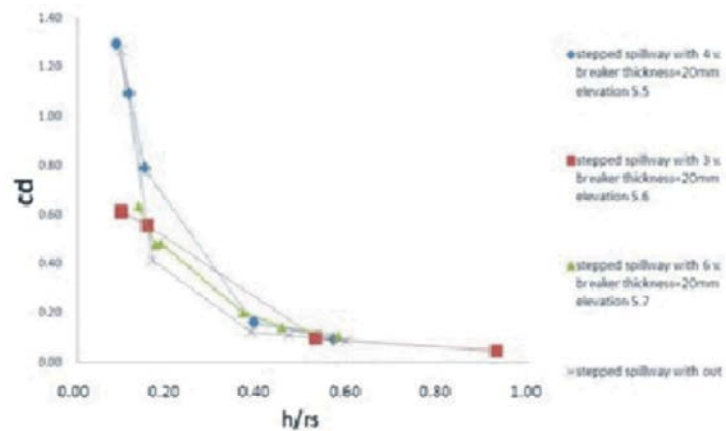Pic. 1: Experiment with three vortex breaker on stepped morning spillway

Fig. 11. C$_d$ against h/rs (stepped spillway) high height v. breaker thickness 20mm
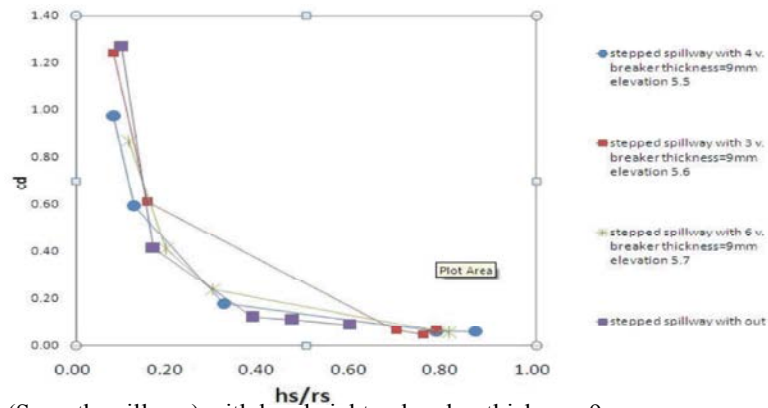

Fig. 12: C$_d$ against H/R$_s$ (Smooth spillway) with low height v. breaker thickness 9 mm
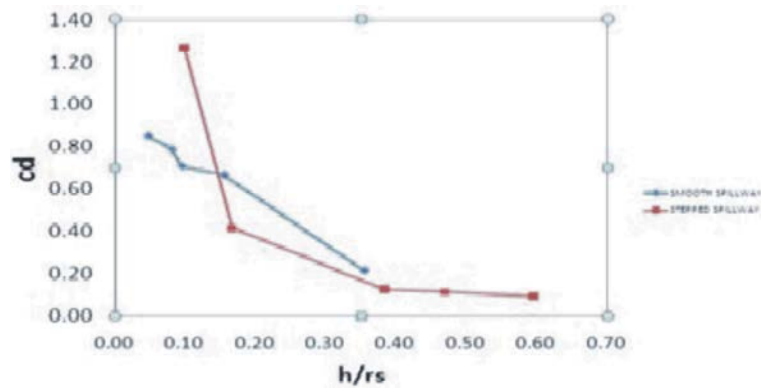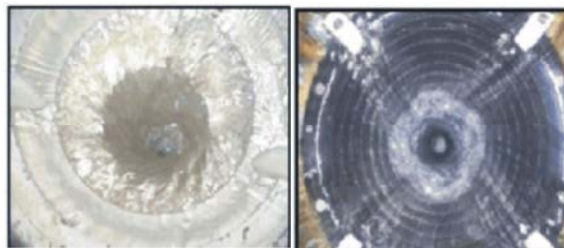

Fig. 13: C$_d$ against H/R$_s$ (stepped spillway) and smooth spillway without vortex breaker

Pict. 2 : low passing through Stepped spillway (stepped spillway) Picture (3). Flow passing through Stepped spillway(stepped spillway) with creation vortex at down side of spillway

Table 1: Information of experiment which has be done

Type of spillway	Different discharge	Type of vortex breaker	Arrangement	Thickness of vortex breaker	Number of Experiments
4	5	5	3	1	300

Table 2: Effect of vortex breaker on increasing Discharge Coefficient (with Using 6 vortex breaker)

Shape of vortex breaker	C_d	H/R_s	$Q_{(L/s)}$	Shape of spillway	EFFICIENCY increasing rate
Without vortex breaker	0.41	0.09	2.26	Smooth	1
Triangular long	0.81	0.092	2.26	Stepped	1.18
Triangular short	0.44	0.172	2.26	Stepped	1.07
Triangular middle	0.62	0.141	2.26	Stepped	1.14
Ogee shape	0.69	0.12	2.26	Stepped	1.22
Rectangular	0.61	0.095	2.26	Stepped	1.09

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

C_{2v}	C_{Iv}	l_c/d	t_v/d	l_v/d	n_c/d	C_d	H/R_s	Discharge (lit/s)
1	1	0	0	0	0	0.87	0.08	2.03
1	1.62	0	0.025	0.2	6	1.38	.073	2.03
0.69	1	0	0	0	0	0.59	0.17	2.03
0.28	1.62	0.06	0.025	0.2	3	0.63	0.13	2.03
0.929	1	0.086	0	0	0	0.79	0.08	2.03
0.543	1.32	0.086	0.025	0.20.2	3	0.81	0.079	2.03
0.81	1	0.11	0	0	0	0.69	0.102	2.03
0.449	1.32	0.11	0.025	0.2	3	0.67	0.12	2.03
1.02	1	0.028	0	0	0	0.86	0.08	2.03
0.398	1.62	0.028	0.025	0.2	6	0.89	0.098	2.03

Table 4: Design formula for Stepped morning spillway

No	Equations	Descriptions
1	$cd = 0.073 * \left(\dfrac{H}{rs} \right)^{-1.218}$	C_d for spillway with 4th Vortex breaker (with ogee shape)
2	$cd = 0.0578 * \left(\dfrac{H}{rs} \right)^{-1.125}$	C_d for spillway with 3 Vortex breaker (with ogee shape)
3	$cd = 0.0278 * \left(\dfrac{H}{rs} \right)^{-1.678}$	C_d for spillway with 6 Vortex breaker (with ogee shape)

For stepped spillway the equation is as below:

$$C_d \; 0.016 * \left(\frac{H}{rs} \right)^{-1.629} * 1.949 (Fr)^{0.364} \tag{15}$$

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.

For studying effect of different shapes of vortex breaker and different arrangement of guide pier on crest of spillway, some different experiments were done. According to these runs, the best efficiency of discharge coefficient is related to ogee shape as vortex breaker with sixth number on crest. Table (1) shows the result of different discharge coefficient:

Due to Table (2), the best result of utilizing vortex breaker is related to ogee shape vortex breaker which has better effect on passing stream lines through spillway. In

the other words, minimum eddies will occur when stream line move smoothly near semi short through Shaft spillway body and one boundary line with lower friction will appeared subsequently.

For better understanding and applicability of Experiments, According to number (10), some coefficient were developed which are present as Table(3).

In this table Lc is number of steps in spillway barrel, Tv is thickness of vortex breaker, L0 is length of vortex breaker, d is structure diameter and H/Rs is submersible ratio.

According to table (3), the best discharge coefficient is related to smooth spillway with 6 vortex breaker ($C_d = 1.38$) and second better C_d is stepped spillway, with 12 steps and 6 vortex breaker.

As a result, It is revealed that when steps chamber will be used emptying parameter decrease averagely about 30 %, but when vortex breaker with 6 arrangement and ogee shape will be utilized , suitable condition for passing

flow will be appeared. In the other words, using steps chamber has very good efficiency, especially when cavitations risk should be considered to.

In order to use these result for using vortex breaker, some equation for calculating C_d based on Submersible ration have been developed. These formulas are estimate for twelve steps spillway with different vortex breaker:

CONCLUSIONS

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

Maximum risk of flow rate is magnitude at 1/3 down side of shaft, magnitude velocity is occurred at the end steps of stepped chamber and also will take place at ¼ of stepped semi short through Shaft spillway.

According to simulation, height and width of each step on stepped chamber has great effect on floe regime, specially when flow regime change 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 straight forward, 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 suppresses water level oscillations.

Using Stepped semi short through Shaft 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. According to the runs, Although, stepped chamber on spillway decrease flow rate and also stepped chamber deduce cavitations risk, using vortex breaker with ogee shape increase flow rate till 22%.

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