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Experimental Study of Coupled Parabolic Weir over Flow and Gate under Flow Rate

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Abstract

A combined flow through composite hydraulic structure or device represents a very important problem as a result of the interaction between over flow rate and under flow rate. In the present study, many experiments were implemented in the hydraulic laboratory considering several variables such as hydraulic variables and geometrical variables to investigate the overlapping between weir and gate having a parabolic shape. It is found that the weir and gate cross sectional area of flow have significant effect on coefficient of discharge of combined hydraulic structure. It is also very necessary to take the effect of geometrical parameter and the parameter expressed in this study in terms of ratio (y/H). This ratio has a primary effect on discharge coefficient. This study indicates that the overlapping between flow velocity of weir and gate respectively is central to value of discharge coefficient. This study mentions the effect of viscosity on coefficient of discharge in terms of Reynold number. Also, this study proves that the parabolic shape more efficiency as compare with regular shape.

Keyword: Parabolic weir, Parabolic gate, Composite hydraulic structure, Flume.

Introduction

The extent of use for gates and weirs for flow control and discharge measurement in open channel flow is very large. Problems such as sedimentation and depositions are lessened by these combined gates and weirs as stated by Alhamid et al. (1997). Not a large number of works dealing with overflow and underflow as discharge elements exist, such as Chow (1959), Ahmed (1985), Naudascher (1991), Negm et al. (1994). These works go over the characteristics of the combined flow over rectangular contacted weirs and below inverted triangle weirs.

An investigation was done over the effect of a notch angle over a triangular opening when it is used above and below the rectangular opening by El-Saiad et al (1995). It was concluded that a triangular above a rectangular opening is far more efficient than reversed. A regression equation was presented by Alhamid et al. (1996) to predict the discharge over contracted rectangular weirs and below triangular gates. The characteristics of combined flow over contacted weirs and below triangular gates of unequal shape were analyzed by Negm (1995) with unequal contractions. Negm (1996) presented a discharge prediction for combined flow over suppressed rectangular wires and below gates.

The effects of the hydraulic and geometrical parameters on the combined discharge and presented discharge equations for triangular weirs above rectangular contracted gates and contracted rectangular wires above triangular gates were discussed by Negm et al. (1997). It was proved that significant errors are produced from the prediction of the combined discharge through the use of common discharge coefficients. Combined-submerged flows were also analyzed by Negm et al. (1999), Alhamid (1999), Negm (2000), Negm et al. (2000a). The transition from free combined flow to submerged combined flow was investigated by Albrahim et al. (2000).

Villemonte, (1947) proved that the triangular and parabolic weirs are a more accurate measuring device than proportional and rectangular types. Also, the sharped-crested submerged weirs can be used in practice with confidence, if certain design and operational specifications are satisfied.

The characteristics of the combined flow parabolic over weirs and below parabolic gates of unequal contraction are studied in this paper. Different geometrical parabolic shape combinations are used. Effects of hydraulic and geometrical parameters are investigated. Also, an effect of viscosity on the coefficient of discharge is discussed. Comparison between parabolic shape and regular shape to explain the effect of them on the value of coefficient of discharge is performed.

Fluid Principle Consideration

To determine the discharge through combined device (parabolic weir and parabolic gate) for the free flow situation, the discharge represents the incorporation of both weir and gate

$$Q_{theo} = Q_W + Q_g \quad \text{--------------------} \quad \text{- - (1)}$$

To calculate the theoretical discharge through weir (Bos,1989)

$$Q_w = \frac{\pi}{2} \sqrt{f\,g}\,h^2 \quad \text{------------------} \quad \text{- (2)}$$

To calculate the discharge through gate (Streeter, 1983)

$$Q_g = V\,A = \sqrt{2\,g\,H}\;A \quad \text{------------------} \quad (3)$$

$$Q_{act} = c_d\;Q_{theo} \quad \text{-------------------------} \quad (4)$$

$$Q_{act} = c_d\;\left[\frac{\pi}{2}\sqrt{f\,g}h^2 + \sqrt{2\,g\,H}\;A\right] \quad \text{------------------------} \; (5)$$

Where:

H: upstream water depth of the gate (H= d + y + h)

h: water head above sharp crest weir

y: vertical distance between weir and gate

d: water depth of gate opening

A: cross sectional area of the gate (cross sectional area of the flow through the gate)

V: flow velocity through gate

f: focal distance

g: acceleration due to gravity

Q_w : *Discharge of wier*

Q_g: Discharge of gate

Q_{theor}: Theoretical discharge (flow rate)

Q_{act}: Actual discharge (flow rate)

c_d: Coefficient of discharge, assuming that one coefficient of discharge can be applied to the combined flow.

Figure (1) shows the definition of combined flow over weir and under gate that is considered in the present study.

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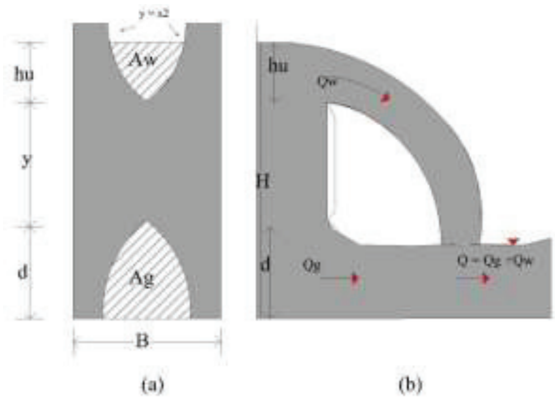

Figure 1. Definition Sketch for Combined Free Flow over Weirs and below Gates (a) Cross Section (b) Longitudinal Flow and Geometry Section.

Experimental Study

The experiments were carried out in a rectangular glass sided flume with dimension of length equal to 200cm, depth of 15cm and width of 7.5cm. The water depth is measured by the scale fixed in the wall of the flume while the discharge is measured by volume method. Table (1) reviews the dimensions of the model that fabricate from wood material and table (2) reviews all the information that was obtained from experimental study performed in laboratory. The following procedures are adopted in laboratory test.

1- The flume is always in horizontal position.

2- The models were fixed into flume at distance 80cm from the beginning of the flume.

3- The tail gate was removed to satisfy the free flow condition.

The above procedure was repeated for all models.

Table 1: The Tested Model Dimensions and Details of Parabolic weir and Gate

Model No.	Weir Depth (d) (cm)	Gate Depth (cm)	hu (cm)	y (cm)	H (cm)	Area of Gate (Ag) (cm^2)	Area of Weir (Aw) (cm^2)	Velocity (m/sec)
1	2	2	1	6	9	3.63	1.15	1.329
2	3	3	1	4	8	6.442	1.15	1.253
3	3	3	2	4	9	6.442	3.63	1.329
4	4	4	1	2	7	9.761	1.15	1.172
5	4	4	2	2	8	9.761	3.63	1.253
6	2	4	1	4	9	9.761	1.15	1.329
7	4	2	1	4	7	3.63	1.15	1.172
8	4	2	2	4	8	3.63	3.63	1.253
9	4	2	3	4	9	3.63	6.442	1.329
10	2	3	1	5	9	6.442	1.15	1.329
11	3	2	1	5	8	3.63	1.15	1.253
12	3	2	2	5	9	3.63	3.63	1.329
13	3	4	1	3	8	9.761	1.15	1.253
14	4	3	1	3	7	6.442	1.15	1.172
15	4	3	2	3	8	6.442	3.63	1.253
16	4	3	3	3	9	6.442	6.442	1.329

Table 2: Results of the Experimental Models

Model No.	Ag/B.H	Aw/B.H	$V/(g.B)^{(1/2)}$	y/H	Q_{theo} (l/sec.)	$Q_{act.}$ (l/sec.)	Cd
1	0.054	0.017	1.549	0.667	0.507	0.403	0.795
2	0.107	0.019	1.461	0.500	0.832	0.606	0.728
3	0.095	0.054	1.549	0.444	0.954	0.622	0.651
4	0.186	0.022	1.366	0.286	1.169	0.772	0.661
5	0.163	0.061	1.461	0.250	1.321	0.787	0.595
6	0.145	0.017	1.366	0.444	1.322	0.812	0.614
7	0.069	0.022	1.549	0.571	0.450	0.280	0.622
8	0.061	0.061	1.633	0.500	0.553	0.419	0.758
9	0.054	0.095	1.713	0.444	0.704	0.457	0.649
10	0.095	0.017	1.461	0.556	0.881	0.592	0.672
11	0.061	0.019	1.549	0.625	0.479	0.369	0.771
12	0.054	0.054	1.633	0.556	0.581	0.483	0.831
13	0.163	0.019	1.366	0.375	1.247	0.767	0.615
14	0.123	0.022	1.461	0.429	0.780	0.481	0.617
15	0.107	0.061	1.549	0.375	0.905	0.620	0.685
16	0.095	0.095	1.633	0.333	1.077	0.815	0.757

Sixteen models are tested involving the following limitations: $0.222 \leq y/H \leq 0.667$, $0.054 \leq Ag/B.H \leq 0.186$, $1.366 \leq V/(gB)^{(1/2)} \leq 1.713$, $0.017 \leq Aw/B.H \leq 0.095$, $0.25 \leq hu/d \leq 1.5$. Models are made of wood sheet 5mm thick beveled along all the edges at 45^0 with sharp edges of thickness 1mm. Models are fixed to flume using plexiglass supports. The selection of the flume and model material was based on the available laboratory facilities. In each test, combined flow rate, $Q_{act.}$, head over the weir, hu, and upstream flow depth, H, are measured under free flow conditions. The parabolic that adopt in present study have the following equation$(y = x^2)$.

Results and Discussion

Water control structure or irrigation hydraulic structure play a vital role in determining the interaction between the over flow rate and under flow rate which can be described by flow over weir and flow under gate. Actually, weir and gate represent the common and significant hydraulic structure used to measure and control flow. Flow interaction can be assessed by determining the discharge coefficient of combined flow. The theoretical discharge flow rate $Q_{theor.}$ is computed using equations (1 to 3), while the actual discharge flow rate $Q_{act.}$ is estimated from the experimental model. Then, the discharge coefficient, C_d is calculated using equation (4). Figure (2) shows the variation of discharge coefficient, C_d with area of the gate. The value of the area of the gate is non-dimensionalzed by division of the hydraulic cross sectional area (B.H). It is clear from figure(2) that as the gate cross sectional area of flow increases the coefficient of discharge, C_d decrease due to inverse proportional between C_d and flow cross sectional area of flow.

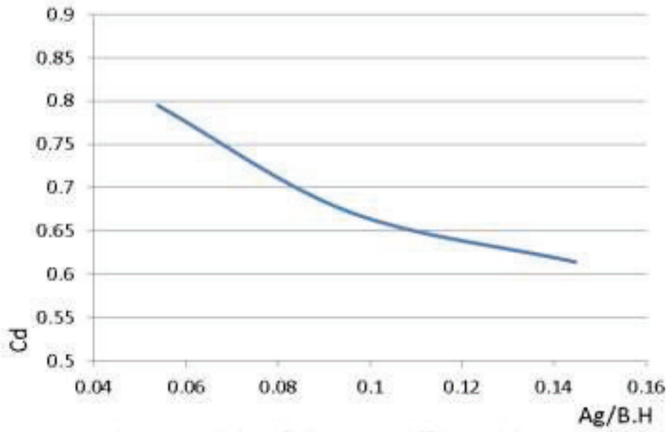

Figure 2. Variation of Discharge Coefficient with Gate Area for Aw/B.H=0.01277

Figure (3) shows the variation of discharge coefficient, C_d with area of the weir. The value of the area of the weir is non-dimensionalzed by division of the hydraulic cross sectional area (B.H). It is observed from figure (3) that as the weir cross sectional area of flow increases the value of Cd increases. This is due to the fact that, the increase in the value of (Aw/B.H) results from increasing in depth of flow in the sharped-cross weir (hu) by considering constant value of (B.H). Also, it is clear that the value of (Aw/B.H) explain the interaction between hydraulic (hu) and geometric (Aw) parameters. The depth of flow in the sharp crest weir (hu) controls the cross sectional area of the weir (Aw). So, the variation of the hydraulic parameter (hu) leads to a variation in geometric parameter (Aw).

Figure (4) shows the variation of discharge coefficient, C_d with the distance between weir and gate (y). The value of (y) is non-dimensionalzed by division of the flow depth of flume (H). It is evident from figure (4) that as the ratio (y/H) increases the coefficient of discharge, Cd decreases. The factors which dominate this issue is flow depth in flume (H), geometrical distance between weir and gate(y), flow depth over sharp crest weir (hu), and water depth at gate (d) where (H=h+ y+ d). In this case (h) and (d) are considered as constant, only (y) varying with flow. Therefore, (H) is directly proportional with (y). Generally, C_d are inversely proportional with (H), so that C_d proportional inversely with (y) when (d) and (h) are considered constant.

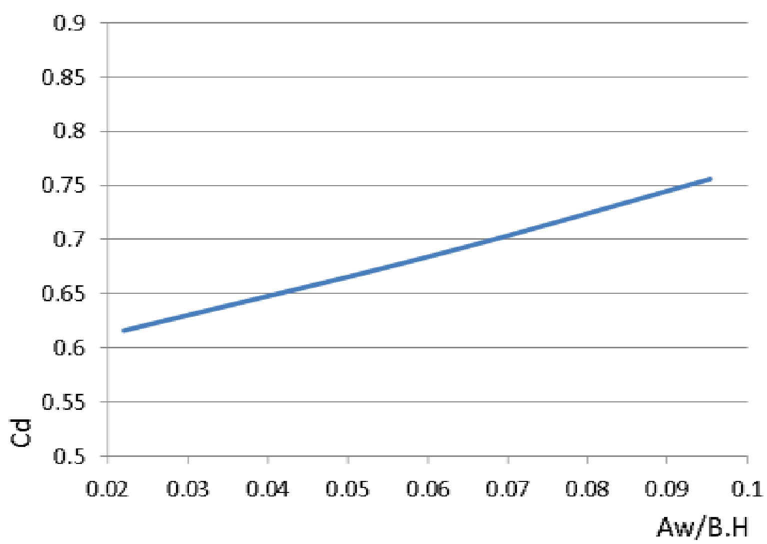

Figure 3. Variation of Discharge Coefficient with weir Area for Ag/B.H=0.07157

Figure (5) shows the variation of discharge coefficient, C_d with the flow velocity. The value of (V) is non-dimensionalzed by division of the value of ($\sqrt{g.B}$). Figure (5) explains that the value of C_d increases with increasing in the flow velocity due to overlapping effect between the flow velocity of the weir and flow velocity of the gate taking into consideration the flow velocity through weir depends on (hu) while in the gate it depends on (H). Also, it should be noted that the increase in the value of (H) in the above figure is due to the increase in the value of (hu).

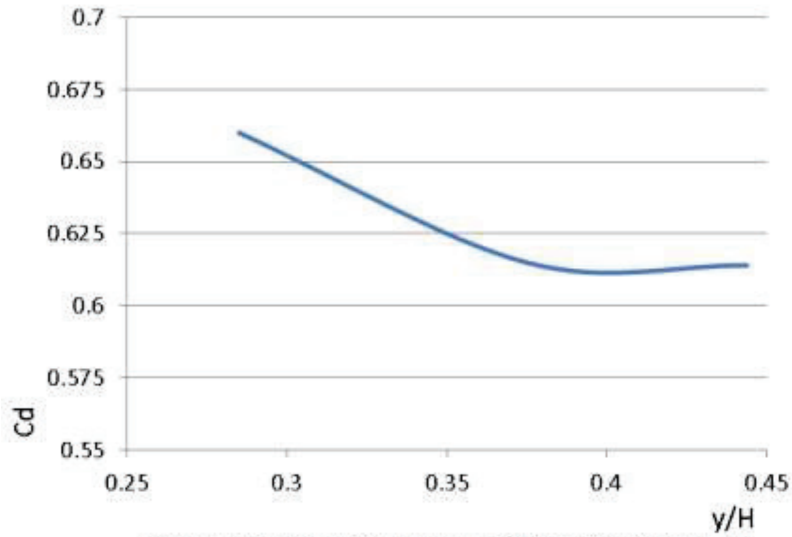

Figure 4. Variation of Discharge Coefficient with Distance (y) for Ag/B.H=0.10845

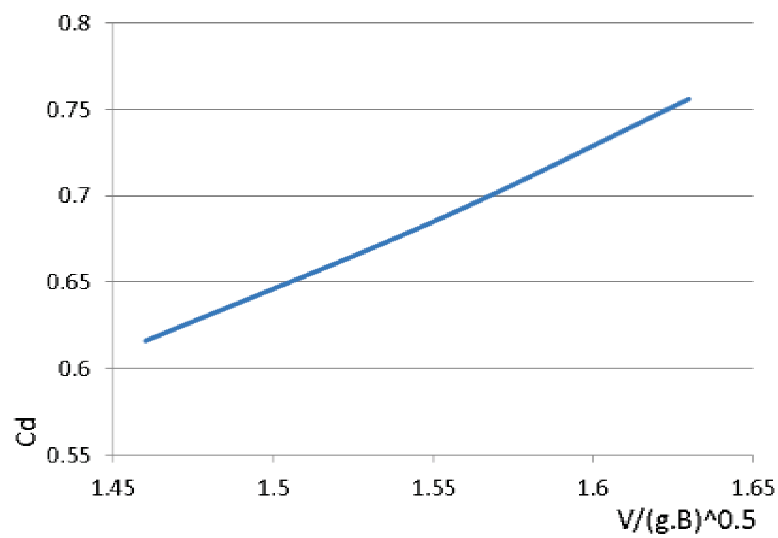

Figure 5. Variation of Discharge Coefficient with Velocity for Ag/B.H=0.07157

The effect of viscosity is studied in terms of the Reynolds number, (R_N= VH/ν), where ν is the kinematic viscosity of the water, (V and H) as defined before. Figure (6) shows the variation of discharge coefficient, C_d with the Reynolds number. It is observed that as the Reynolds number increases the value of C_d increases. This is due to the fact that, the Reynolds number is a function of flow velocity and the value of Cd is proportional to the flow velocity.

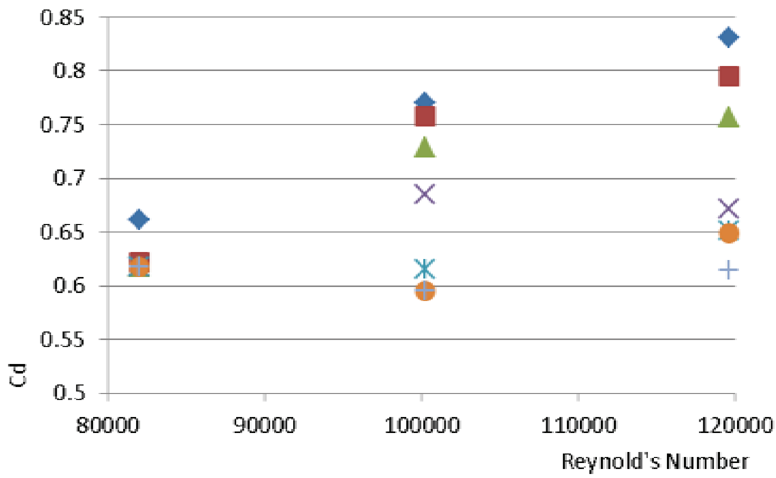

Figure 6. Variation of Discharge coefficient with Reynold's Number

Effectiveness of Parabolic Shape:

In order to explain the importance and effectiveness of the parabolic shape for weir and gate, the results obtained from the present steady should be compared with another regular shape of combined weir and gate. For this purpose six models of constant area of triangular gate and variable area of rectangular weir are designed and executed. The Same procedure of experimental work is applied to the six models to obtain the values of Q_{act}, Hu, and H. The value of $Q_{theor.}$ is computed using equations as in (Alhamid et al., 1996). The value of Cd is calculated by using equation (4). Table (3) shows the dimensions of the six models that fabrication from wood material and review all the information that was obtained from experimental study which was performed in laboratory.

Figure (7) shows all values of coefficient of discharge obtained for both parabolic and regular shape. Table (4) shows the average, minimum, and maximum values of coefficient of discharge for parabolic and regular shape. It is clear from this figure that the coefficient of discharge of parabolic shape is greater than that one of regular shape.

Table 3: Models Dimensions and Details of Regular Shape

Model No.	y/d	h/d	b/b1	h/b	b1/d	Q_{act} (l/sec)	Q_{theor} (l/sec)	C_d
1	0.7	0.898204	0.5	1.2	1.5	0.760	1.257	0.605
2	0.7	0.598802	0.75	0.533333	1.5	0.699	1.158	0.604
3	0.7	0.598802	1	0.4	1.5	0.704	1.282	0.549
4	1	0.598802	0.5	0.8	1.5	0.729	1.112	0.656
5	1	0.449102	0.75	0.4	1.5	0.713	0.995	0.716
6	1	0.299401	1	0.2	1.5	0.706	0.945	0.747

Table 4: Coefficient of Discharge for Parabolic and Regular shape

Type	C_d		
	Average	Minimum	Maximum
Parabolic	0.689	0.595	0.831
Regular	0.646	0.549	0.747

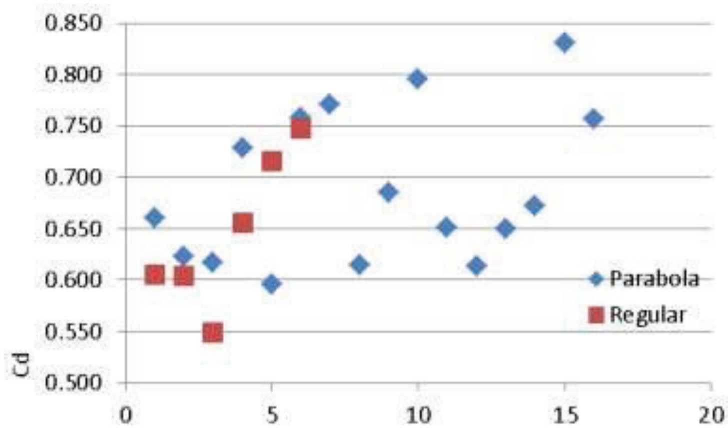

Figure 7. The value of Cd for Parabolic shape and regular shape (Triangle gate and Rectangular Weir)

Conclusion

1- The cross sectional areas of flow of both weir and gate respectively have major effect on the estimated value of discharge coefficient.

2- The value of (H) is sensitive to the value of (y) and therefore the ratio (y/H) has important effect on discharge coefficient.

3- The interaction between the over flow velocity and under flow velocity have major effect on coefficient of discharge.

4- It is very important to compute coefficient of discharge for composite hydraulic structure due to overlapping between several variable.

5- The effect of viscosity has an obvious start of after R_N >100000.

6- It is evident that the parabolic shape is more efficient than other regular shape regarding to the coefficient of discharge.

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