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CHARACTERISTICS OF FLOW THROUGH WEIRS CONTROLLED BY A GATE WITH AN OPENING*

Amany A. Habib**

Water & Water Structures Eng. Dept., Faculty of Eng., Zagazig University, Egypt

ABSTRACT:

Fayoum standard weirs have pipes to empty the canals. These pipes can be used to convey much water in the downstream side. When the canal is multi-purposes one (used for irrigation, navigation, power generation, domestic and industrial water supply….etc), the gate over weir will be used to control the discharge required for different purposes. An experimental study was carried out to investigate the characteristics of the flow over the weir controlled by a sluice gate and with circular opening. Five weir models with different opening dimensions were tested in a horizontal laboratory flume. The same weir height is used with each opening. Each opening is tested with four gate openings. The results of the flow over the weir with a circular opening were compared with those of the weir without an opening and the free weir (without a controlled gate). The dimensional analysis was used to correlate the discharge coefficient to the other relevant flow and opening parameters. Multiple regression equations based on dimensional analysis theory were developed for computing the discharge coefficient and the discharge of the passing through the opening and below the gate over the weir. The developed equations are compared to the experimental data and the comparison proved a good reliability and high accuracy.

KEY WORDS: Fayoum weir, Weir opening, Free flow, Controlled gate, and Discharge Coefficient.

CARACTÉRISTIQUES DES FLUX DE BARRAGES CONTROLE PAR UNE BARRIERE AVEC UNE OUVERTURE

RÉSUMÉ:

Fayoum déversoirs standard ont conduites à vider les canaux. Ces tuyaux peuvent être utilisés pour véhiculer beaucoup d'eau dans la partie aval. Lorsque le canal est multi-application d'une (utilisée pour l'irrigation, la navigation, la production d'électricité, l'approvisionnement en eau domestique et industrielle .... etc), la grille au-dessus du déversoir sera utilisé pour contrôler l'évacuation exigée à des fins différentes. Une étude expérimentale a été réalisée pour étudier les caractéristiques de l'écoulement sur le déversoir contrôlé par une vanne et à ouverture circulaire. Cinq modèles de déversoir avec des dimensions d'ouverture différentes ont été testées dans un canal de laboratoire horizontale. La même hauteur du déversoir est utilisé à chaque ouverture. Chaque ouverture se déguste avec quatre ouvertures de portes. Les résultats de l'écoulement au-dessus du déversoir d'une ouverture circulaire ont été comparés avec ceux du déversoir sans ouverture et le déversoir libre (sans porte contrôlée). L'analyse dimensionnelle a été utilisé pour corréler le coefficient de débit de l'écoulement d'autres paramètres pertinents et d'ouverture. Équations de régression multiple basé sur la théorie de l'analyse dimensionnelle ont été mis au point pour le calcul du coefficient de décharge et la décharge du passage à travers l'ouverture et au-dessous de la grille au-dessus du déversoir. Les équations développées sont comparés aux données expérimentales et la comparaison s'est avéré une bonne fiabilité et une haute précision.

MOTS CLÉS: Fayoum barrage, ouverture Weir, débit gratuit, portail contrôlé et coefficient de décharge.

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** Contact author (amanyhabib89@yahoo.com, +2 01001658377)

1 INTRODUCTION

Gates and weirs have been used extensively for flow control and discharge measurement in irrigation channels. Studies concerning the use of sluice gate are introduced, e.g. by Rajaratnam [17] (1977), French [7] (1986), Swamee [20] (1992). Regarding the flow weirs many studies have been found such as Herschy [11] (1978), Swamee [21] (1988), Bos [5] (1989), and Munson et al [13] (1994). Weirs and gates may be combined together in one device yielding a simultaneous flow over the weir and below the gate. Problems concerning sedimentation and depositions are minimized by combined weirs and gates as mentioned by Alhamid et al. [3] (1997), Fadil [6] (1997) developed a meter for the combined flow through contracted sluice gate and weir, also combined submerged flow through weirs and below gates were analyzed by Negm et al. [16] (1999), Negm [14] (2000). The characteristics of the combined flow and over weirs and below gates of equal contraction are discussed by Negm et al. [15] (2002). Hayawi et al. [10] (2008) studied the characteristics of combined flow over a triangular weir and below a rectangular gate. Samani and Mazaheri [19] (2009) studied the simultaneous flow over weir and under gate, in particular, the determination of the stage-discharge relationship. Models of sharp-edged weirs and gates with no lateral contraction are combined. It was found that the model is able to predict the stage – discharge relationship with reasonable accuracy. Weirs may be used for distribution of water to canals for irrigation, reducing the hydraulic slope in the canals, reducing the acting head on regulators. With the increase of cultivated area served by canals, water requirements increased. As a result the capacity of the existing weirs built on those canals and the embankment height of the canals themselves upstream of the weirs became insufficient to pass the increase of required water. Therefore, the existing pipes at the bottom for emptying the canals used to pass extra required flow downstream. Clear over fall weirs are common in irrigation systems in Egypt. Works concerning the flow over weirs have been mentioned by Bos et al. [4] (1986), Goguş et al. [8] (2006), Hager and Schwalt (1994)[9], Mohamed [12] (2005), Sargison and Percy [18] (2009), and many others. Wolters et al. [22] (1987)made serious attempts to calculate the discharge for a system that consisted of a specific weir and a pipe. They made a distinction between flow over the weir, which can be calculated rather accurate, and the flow through the pipes, which is far less reliable. They suggested rating curves for all weirs they studied. Abdel Halim et al. [1] (1991) calibrated experimentally the flow over existing Fayoum weirs with orifices. They suggested that, calibration must be based only on water head over the crest of the weir, which is the only measurable parameter in the field. Abozeid et al [2] (2010) investigated experimentally the flow over weir with bottom opening to obtain a relationship between the flow passing through the pipe and over the weir.
The main objective of this research is to study the effect of the opening dimensions on the discharge coefficient of the flow over a weir which is controlled by a sluice gate and the effect of the flow controlled gate. Also to develop equations for computing the discharge and the discharge coefficient through the combined device.

2 COLLECTION OF EXPERIMENTAL DATA

The experimental work of this study was conducted using a re-circulating adjustable flume of 3 m long, 30 cm deep and 10 cm wide. The discharges were measured using pre-calibrated orifice meter fixed in the feeding pipeline. The tailgate fixed at the end of the flume was used to control the tail-water depth of flow. The weir model dimensions were kept constant at (10cm height, 5cm top width, 10cm bottom width). The model was fixed in the middle third of the flume between its two side-walls as seen in Fig. (1). Six weir models are used with different circular opening diameters (0.0, 0.5, 0.75, 1.0, 1.75, 2.0 inch). The models of the weir are made of wood and the openings made of PVC pipes. The wood was painted very well by a proof material (plastic) to prevent wood from volume changing by absorbing water. The center line of the opening is fixed at the middle of the weir height. Fig. 1 shows definition sketch of the models used in the experiments. Each model was tested using five different gate openings and five discharges for each gate opening. A typical test procedure consisted of a gate opening was fixed and a selected discharge was allowed to pass then the tailgate was adjusted until a free hydraulic jump is formed just down stream the weir. Once the stability conditions were reached, the flow rate and water depths upstream and at the vena contracta downstream of the weir were recorded. These steps were repeated for different discharges and different gate openings and so on till the required ranges of the parameters being under investigation were covered. The ranges of the experimental data were as follows: Froude numbers (1.5- 3.0), G/P (0.1- 0.35), d/P (0.123-49) and Hu/P (1 – 3).

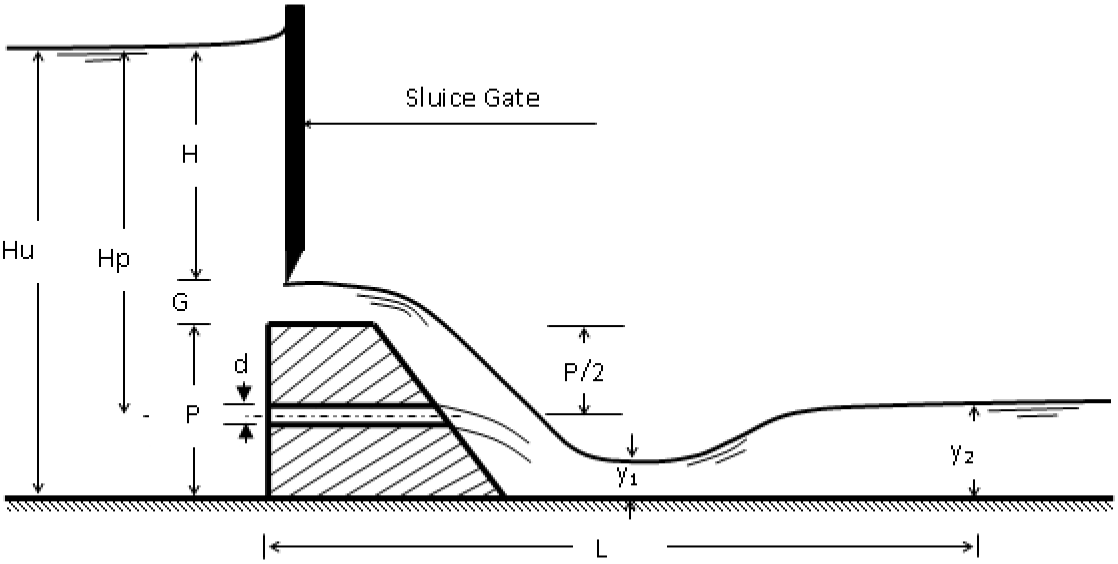

Fig. (1) Definition sketch

3 THEORETICAL APPROACHES

3.1. Discharge Equations Based on Energy Principles

The theoretical discharge over a rectangular weir controlled by a sluice gate without a lateral contractions and a free hydraulic jump in the downstream can be described referring to Fig. (1) as follows:

$$Qw_{the} = G \times b \times \sqrt{2gH} \quad \text{.................(1)}$$

In which Qw_{the} is the theoretical discharge passing over the weir and below the gate, G is the gate opening, b is the width of the weir, g is the gravitational acceleration and H is the upstream head over the gate. Also, the flow through the pipe is governed by the following equation for the orifice discharge:

$$Qp_{the} = \frac{\pi}{4} d^2 \times \sqrt{2gH_P} \quad \text{..................(2)}$$

In which Qp_{the} is the theoretical discharge through the pipe, d is the diameter of the opening, g is the gravitational acceleration and Hp is the head over the pipe centerline , see Fig. (1).Thus, any relation that controls the flow passing through the combined device (Qc_{act}) of the weir and pipe must use these equations to illustrate the interaction that happened in between. The following equation may be used in providing a relation between discharge over weir and discharge through opening:

$$Qc_{act} = (Qw_{the} + Qp_{the}) \times C_d \quad \text{.........(3)}$$

Then

$$C_d = \frac{Qc_{act}}{Qc_{the}} =$$

$$= \frac{Qc_{act}}{\left(G \times b \times \sqrt{2gH} + \frac{\pi}{4} d^2 \times \sqrt{2gH_P} \right)}$$

....(4)

Where C_d, is the coefficient of discharge of the combined device.

3.2. Dimensional Analysis

A physically pertinent relation between the discharge coefficient and the other dependent parameters may be found by dimensional analysis. The non-dimensional relationship is also useful for checking the sensitivity of the different parameters which affect the phenomenon. The functional relationship of the discharge coefficient C_d may be expressed by:

$$\Phi\ (b,\ P,\ H,\ Hu,\ G,\ v_1,\ d,\ \rho,\ \mu,\ g,\ C_d)=0 \quad \ldots\ldots(5)$$

where b is the width of the weir, P is the height of the weir, H is the upstream head over the gate, Hu is the upstream water depth, G is the gate opening, v_1 is velocity downstream the weir, d is the diameter of the pipe, ρ is the water density, μ is the dynamic viscosity of the fluid, and g is the gravitational acceleration. Using π-theorem and applying the properties of dimensional analysis, it yields;

$$C_d = f\left(\frac{G}{P}, \frac{Hu}{P}, \frac{d}{P}, F_1\right) \quad \ldots\ldots(6)$$

Where G/P is the relative gate opening, Hu/P is the upstream relative head, d/P is the relative diameter of the opening, and F_1 $\left(= \frac{v_1}{\sqrt{g\,y_1}}\right)$ is the Froude Number down stream the weir.

4. RESULTS AND DISCUSSIONS

4.1 Effect of Relative Diameter (d/P)

Fig. (2) a, b, c, and d shows the variation of downstream water Froude Number F_1, with the discharge coefficient C_d for different values of relative opening diameter d/P (0.0, 0.123, 0.184, 0.245, 0.429, 0.49) at relative gate opening G/P (0.1, 0.15, 0.2, 0.3) respectively. The figures included the case of free weir(classical weir). It is observed that the values of C_d increased with the increase of F_1. It increases also with the increase of d/P due to the increase in flow caused by the pipe. In comparison with the case of free weir, the figure showed higher values of C_d with the presence of the gate as a result to the increase of the U.S water head.

The percentages increase in C_d of the study in comparison with the case of free weir (without gate and openings) and the case without opening are presented respectively in table (1) and table (2).

Table (1): Average percentages of increase of C_d of the flow over weir controlled by a sluice gate and with circular opening compared with free weir.

G/P	% increase in discharge coefficient (C_d)					
	d/P					
	0.0	**0.123**	**0.184**	**0.245**	**0.429**	**0.49**
0.1	4.23	6.30	7.27	7.75	10.45	11.21
0.15	7.01	8.47	9.29	10.12	12.62	13.45
0.20	9.88	11.55	12.38	13.20	15.69	16.52
0.30	15.52	17.18	17.85	18.68	21.01	21.99

Table (2): Average percentages of increase of C_d of the flow over weir controlled by a sluice gate and with circular opening compared with the case of weir without opening.

G/P	% increase in discharge coefficient (C_d)				
	d/P				
	0.123	**0.184**	**0.245**	**0.429**	**0.49**
0.1	1.992884	2.917235	3.38275	5.972115	6.69971
0.15	1.366348	2.13896	2.911572	5.242075	6.014687
0.20	1.517216	2.269702	3.022091	5.291649	6.044013
0.30	1.443186	2.020835	2.73652	4.75751	5.611241

Fig. (3) a, b shows the relation between the relative gate opening and the discharge coefficient C_d for different values of relative opening diameter d/P (0.0, 0.123, 0.184, 0.245, 0.429, 0.49) at F_1 (2, 3) respectively. It is observed that the values of C_d increase with the increase of G/P. It increases also with the increase of d/P as previously noticed from fig. (2).

4.2 Effect of Relative Upstream Depth (Hu/P)

Fig. (4) a, b, c, and d shows the relation between the upstream relative depth Hu/P and the discharge coefficient C_d for different values of relative opening diameter d/P (0.0, 0.123, 0.184, 0.245, 0.429, 0.49) at relative gate opening G/P (0.1, 0.15, 0.2, 0.3) respectively. It is observed that the values of C_d increased with the increase of Hu/P. It increases also with the increase of d/P in comparison with the case of a weir without opening.

Fig. (5) a, b, c, d, e, and f shows the relation between the upstream relative depth Hu/P and the discharge coefficient C_d for different values of relative gate opening G/P (0.1, 0.15, 0.2, 0.3) at relative opening diameter d/P (0.0, 0.123, 0.184, 0.245, 0.429, 0.49) respectively. It is observed that the values of C_d increase with the increase of G/P and the rate of increase increases with the increase of d/P.

5 PREDICTION OF COMBINED DISCHARGE AND DISCHARGE COEFFICIENT

A multiple regression analysis is used for correlating the different dimensionless variables to develop an empirical equation for computing the discharge coefficient of the flow of a weir controlled by a sluice gate with a circular opening. The developed equation can be expressed as follows;

$$C_d = 0.0081\frac{d}{G} + 0.6239\frac{G}{P} + 0.0728\frac{d}{P} + 0.0385\frac{Hu}{P} + 0.4854 \quad \ldots\ldots(7)$$

Also, the predicted values are plotted against the experimental values and the residuals are plotted versus the predicted values as shown in Fig. (6). The results of the model showed well agreement between the experimental and predicted values of C_d (R^2 = 0.959 and R^2 between residuals and predicted values is 5.00155E-11).

A multiple regression analysis is used also to correlate the different dimensionless parameters shown in Eq. (6) to develop an empirical equation for computing the discharge of the combined flow. The developed equation can be expressed as follows;

$$Qt = 13315.47\frac{d}{P} - 13919.56\frac{d}{Hu} - 689.21\frac{Hu}{P} - 49618.06\frac{Hu}{G} + 35936.6\frac{G}{P} + 31.65\frac{Q_w}{Q_P} \quad \ldots\ldots(8)$$

Where Qt is the actual combined discharge in cm^3/sec, Qw/Qp is the ratio between the flow through the controlled gate and the flow through the pipe. This value can be obtained from Fig. (8) Which shows the relation between C_d and Qw/Qp for different values of d/P and G/P by using the computed C_d from Eq. (6) .The predicted values of Qt are plotted against the experimental values and the residuals are plotted versus the predicted values as shown in Fig. (7). The results of the model showed good agreement between the experimental and the predicted values of Qt (R^2 = 0.91 and R^2 between residuals and predicted values is 0.048). The values of residuals are seems to be high but referring to its units (cm^3/sec) it is a reasonable values.

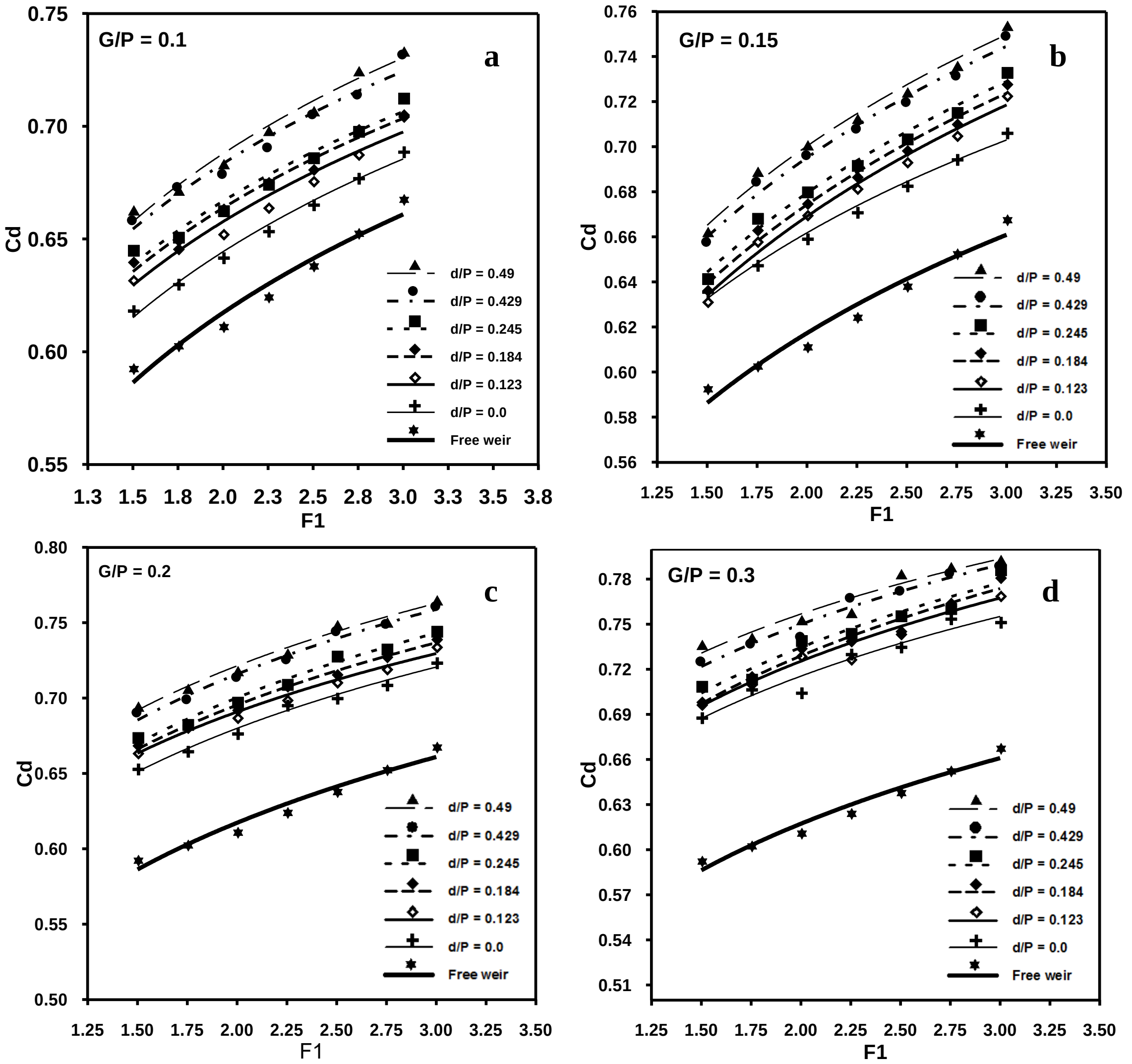

Fig. (2) Relation between F_1 and C_d for different values of d/P at a) G/P = 0.1, b) G/P = 0.15, c) G/P = 0.2 and b) G/P = 0.3

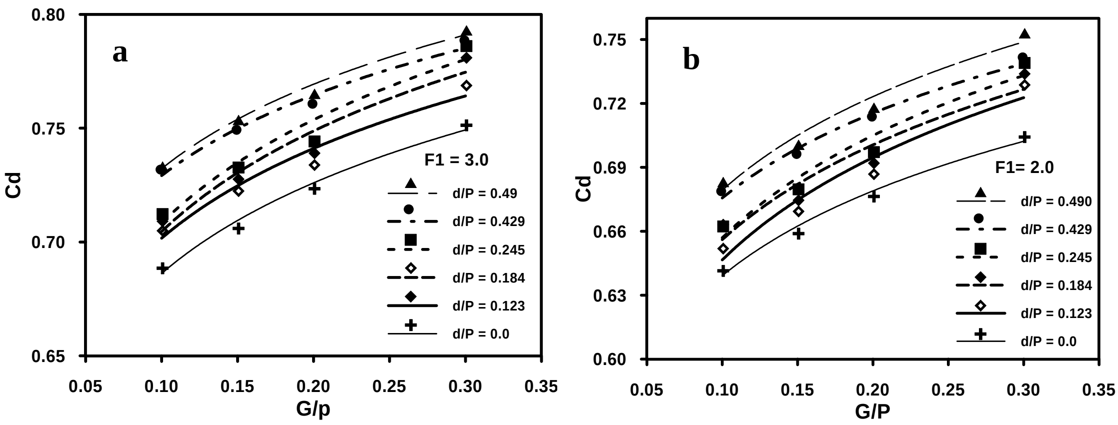

Fig. (3) Relation between G/P and C_d for different values of d/P at
a) F_1 = 2.0, b) F_1 = 3.0

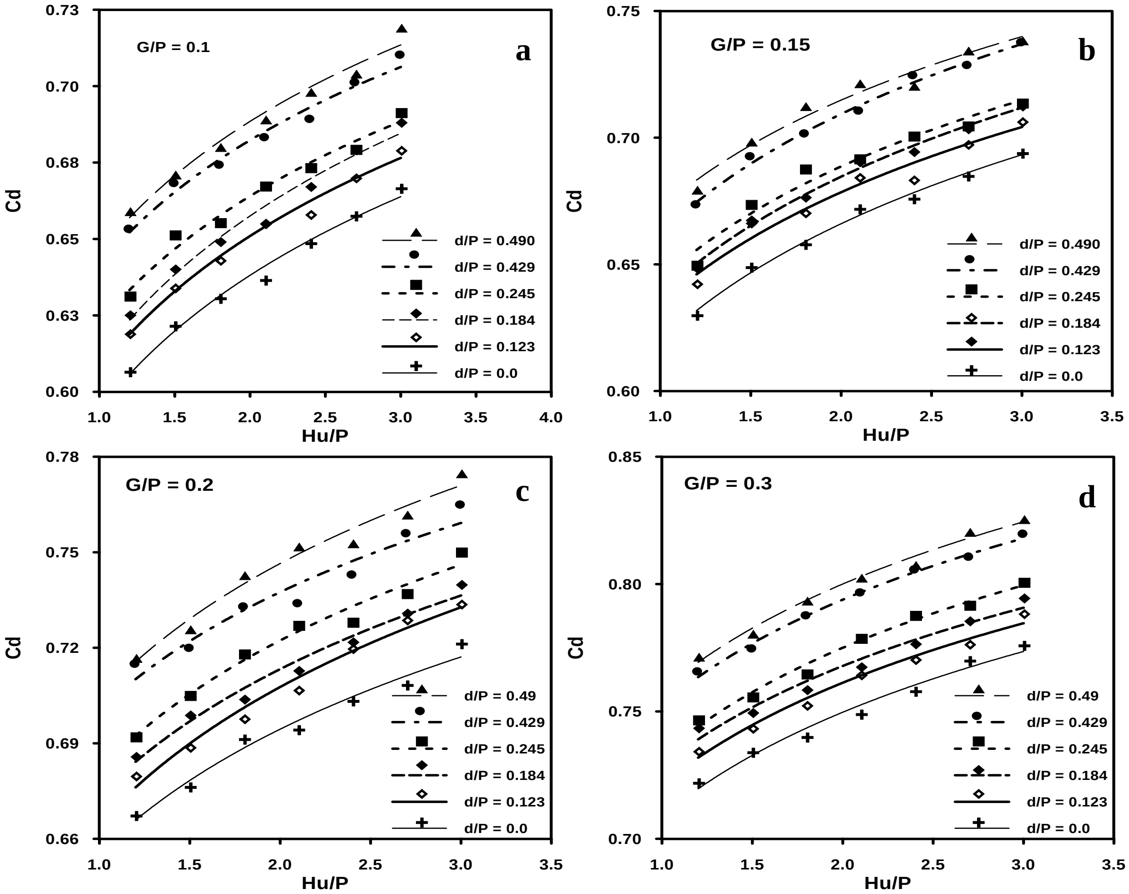

Fig. (4) Relation between Hu/P and C_d for different values of d/P at a) G/P = 0.1, b) G/P = 0.15, c) G/P = 0.2, and b) G/P = 0.3

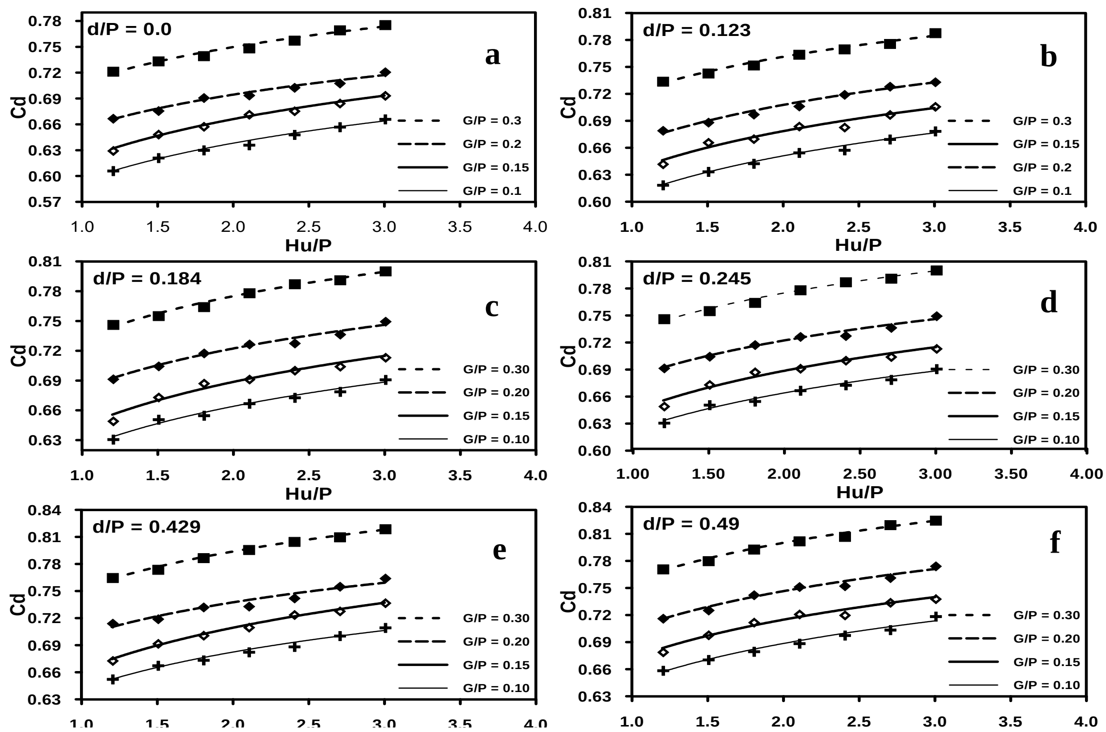

Fig. (5) Relation between Hu/P and C_d for different values of G/P at a) d/P = 0.0, b) d/P = 0.123, c) d/P = 0.184, d) d/P = 0.245, e) d/P = 0.429, and f) d/P = 0.49

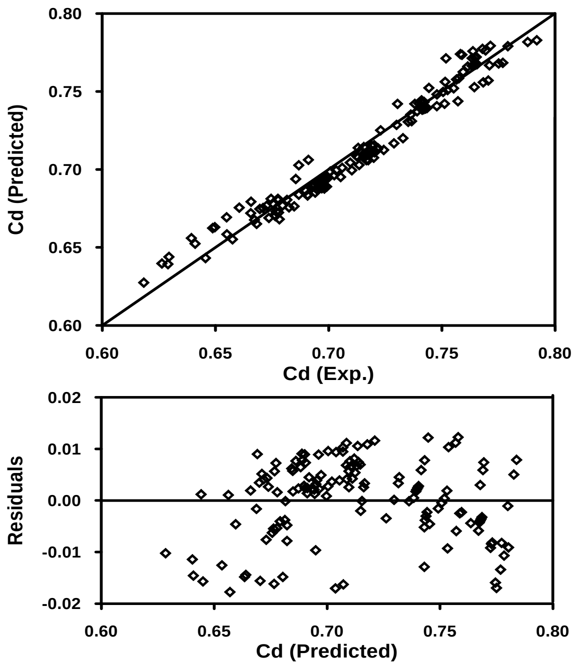

Fig. (6) Results of Equation (7)

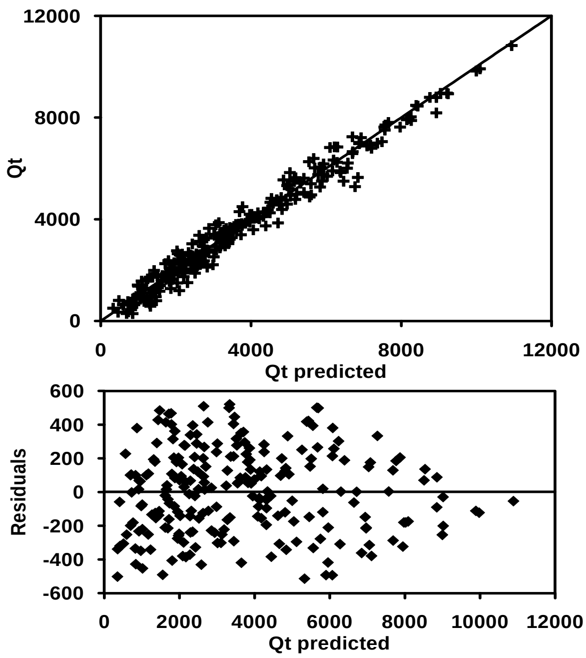

Fig. (7) Results of Equation (8)

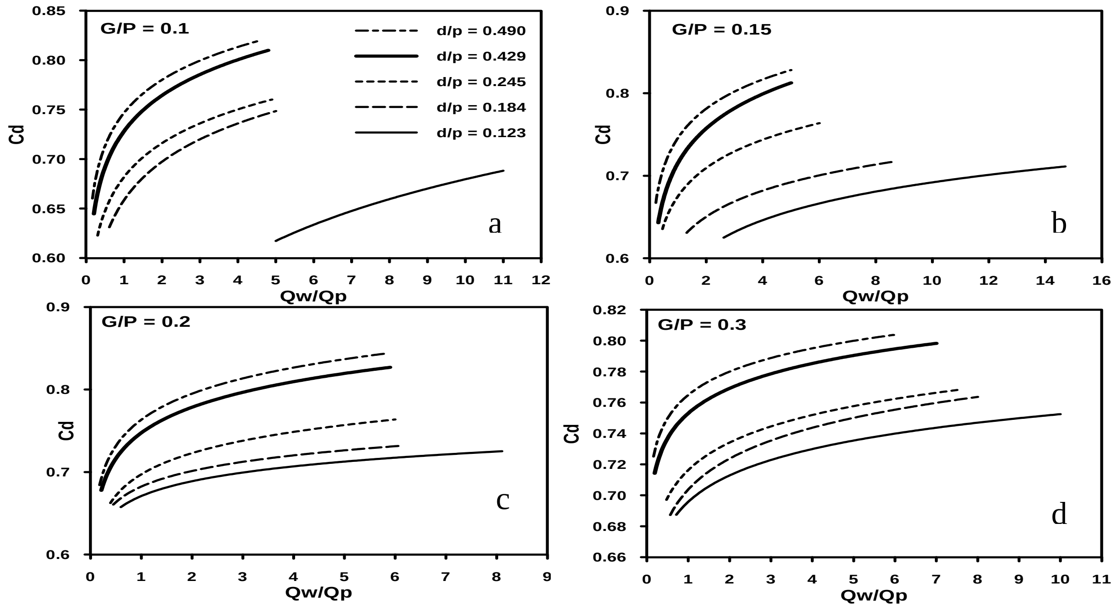

Fig. (8) Relation between Qw/Qp and C_d for different values of d/P at
a) G/P = 0.1, b) G/P = 0.153, c) G/P = 0.2, d) d/P = 0.3

6 CONCLUSIONS

An experimental investigation is conducted in a laboratory flume to investigate the characteristics of the combined flow over a rectangular weir controlled by a sluice gate with a circular opening. An opening of different five diameters is tested. Each model was tested using five different gate openings and five discharges for each gate opening to investigate the effects of the opening relative diameter and the gate relative opening on the discharge coefficient. The results indicated that:

- The discharge coefficient increases with the increase of the downstream Froude number and increases also with the increase of the opening relative diameter d/P for the same G/P as a result of the increase of the discharge caused by the pipe.

- In comparison with the case of free weir, the values of C_d with the presence of the gate are higher for the case without opening due to the increase in U.S water head and the rate of increase increases with the increase of d/P for the same G/P and F_1 due to the increase of the flow.
- The values of C_d increase with the increase of d/P for the same G/P and Hu/P. It increases also with the increase of Hu/P for the same values of G/P and d/P.
- - The using of the gate and the pipe increases the U.S water head and the flow leading to an increase in the discharge coefficient.

A multiple regression analysis is used for correlating the different dimensionless variables to develop empirical equations for computing the discharge coefficient of the flow of a weir controlled by a sluice gate with a circular opening (Eq. 7) and to compute the combined discharge of the device (Eq. 8) with the aid of Eq. 7 and Fig. (8).The results of the models showed well agreement between the experimental and the predicted values.

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