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Discharge Contributions in the Combined Flow of Sharp-Crested Labyrinth Weir-Gate

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Abstract

The rectangular opening which is 20% of the apex wall area works as a gate within a two-cycle sharp-crested labyrinth weir, reduces the effects of immersion upstream, and allows passing sediments. In the result of experimental investigation, the discharge capacity of the labyrinth combined flow related to geometric dimensions; that is where the increase in the sidewall and the apex lengths reduce the immersion, while the discharge increases (23-32%) and when the weir crest level increases about (30%). The combined discharge coefficient decreases when increasing the ratio value of the head to the weir height, its value also decreases by (6-21%) when increasing the sidewall length 3 times. The proposed equation for predicting the combined discharge is within (0.07-0.16%) of the measured discharge. The contribution analysis of each discharge part of this structure indicates the gate passes (40-60%) less than discharged from the weir due to the submergence; Moreover, this state causes head lifting on the weir crest by (26%) and this increases is reflected as an advantage to the weir in its discharging.

Keywords: Flow contribution, Combined Labyrinth weir, coefficient of discharge, dimensional analysis, linear regression.

1. Introduction

Weirs are used for controlling the water in many projects such as irrigation projects and diverting the flow from the main channel. The labyrinth weirs are the type of weir that has a longer length than the normal weir, which has a higher discharge capacity. Many researchers have studied the performance behavior and geometry of labyrinth weirs. Taylor (1968) experimented with 24 different designs of sharp-crested labyrinth weirs. The majority of these models are triangular weirs, with some rectangular and trapezoidal weirs; the comparison of these models with normal sharp-crested weirs shows their ability to measure discharge. Cassidy et al. (1985) studied the efficiency of the triangular labyrinth weir with two cycles of the Boardman spillway and found the results of their study lower than (20-25%) from Hay and Taylor (1970). Tacail et al. (1990) find that two-cycle labyrinth weirs are more effective than a three-cycle labyrinth weir for the same channel width. Sitompul (1993) discovered that trapezoidal labyrinth weirs work better than rectangular labyrinth weirs. Wormleaton and Tsang (2000) found that labyrinth weirs are efficiently aerated compared with normal weirs. Falvey (2003) studied the orientation of the labyrinth weir and showed that can be placed in a normal or inverse position. Willmore (2004) tested the models of labyrinth weirs with two cycles and a sidewall angle (7° to 35°) and found the curve fit for its performance. Tullis et al. (2007) studied three labyrinth weirs with sidewall angles (7°, 8°, and 20°) and discovered an empirical equation for measuring the head in a submerged flow. Abozeid et al. (2010) found the upstream water depth in the case of the combined weir was affected by the downstream water depth when the opening was submerged. Crookston (2010) investigated 30 models of trapezoidal labyrinth weirs with varying sidewall angles from (6° to 35°) to find the discharge coefficient (Cd). Khode and Tembhurkar (2010) recommended the value of the vertical aspect ratio (w/P) should not be < 2 for the trapezoidal weirs and not < 2.5 for the triangular labyrinth weirs. Emiroglu et al. (2011) studied the performance of a labyrinth side weir and presented the curves for the discharge coefficient. Dabling and Crookston (2012) used four models, each with four cycles and a 15° sidewall angle. They suggested an equation for calculating the discharge coefficient (Cd) based on the (Ht/P) ratio. Khode et al. (2012) discovered the regression equation for the trapezoidal labyrinth weir with 2 cycles and a sidewall angle (8° to 30°). Al Saadi (2013) studied the discharge coefficient for combined weirs under multi-cases and the results show the combined rectangular weir with a rectangular opening, combined semicircular weir with a rectangular opening, and combined semicircular weir having a semicircular opening have a high discharge coefficient. Mirnaseri and Emadi (2013) found out the discharge of the rectangular combined labyrinth (weir and gate) is more than the discharge of the combined sharp-crested weir-gate for the values of (Ht/P) less than 0.6. Samani et al. (2013) found the rectangular labyrinth weir has a high efficiency which could be more than the traditional broad-crested weir of about five times. Suprapto (2013) recommended the best design of spillway is the trapezoidal labyrinth weir due to the high capacity. Said and Ouamane (2018) studied physical models of rectangular labyrinth weirs and trapezoidal labyrinth weirs with different entrances (rounded and flat shapes) and they found the rectangular labyrinth weir is more efficient than the trapezoidal weir for all entrance shapes. Ghaderi et al. (2020) conducted numerical and experimental studies. They get to the conclusion that the numerical model can predict the flow behavior of the labyrinth weir with an accuracy of 3.05% relative error. Said and Ouamane (2021) tested the three models of rounded

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entrance labyrinth weir and one model with a flat entrance and found the efficiency of the rounded entrance rectangular labyrinth weir is larger than that achieved of the flat entrance rectangular labyrinth weir by 5%. Samadi et al. (2022) conducted a study to examine the impact of different geometric parameters on the efficiency of triangular and trapezoidal labyrinth weirs. The study involved both experimental tests and numerical simulations.

2. Theoretical Background

The labyrinth weir is used for increasing the effective length of the waterway for the same channel width. Fig (1) shows a top view, section, and schematic view with all dimensions of the Labyrinth weir. The flow-through combined labyrinth weir is individually based on the physical and engineering parameters of each of the weir and the gate as if they work separately Chow (1959) and Subramanya (2009). The summation of the weir discharge (Q_{weir}) and the gate discharge (Q_{gate}) is equal to the total combined flow as presented in Eq. 1:

$$Q_{act} = C_d\left[Q_{weir\ th.} + Q_{gate\ th.}\right] = C_d\left[\frac{2}{3}\cdot\sqrt{2g}\cdot L\, h^{\frac{3}{2}} + a.d\sqrt{2gH}\right] \qquad (1)$$

where: $Q_{weir\ th.}$ = The theoretical flow rate that passes over the weir, $Q_{gate\ th.}$=The theoretical flow rate that passes under the gate, Cd = Discharge coefficient, g = The gravity acceleration, L = Crest length, h = Head of water above weir crest (L), H= Total upstream head, a= Apex width, and d = The height of the opening.

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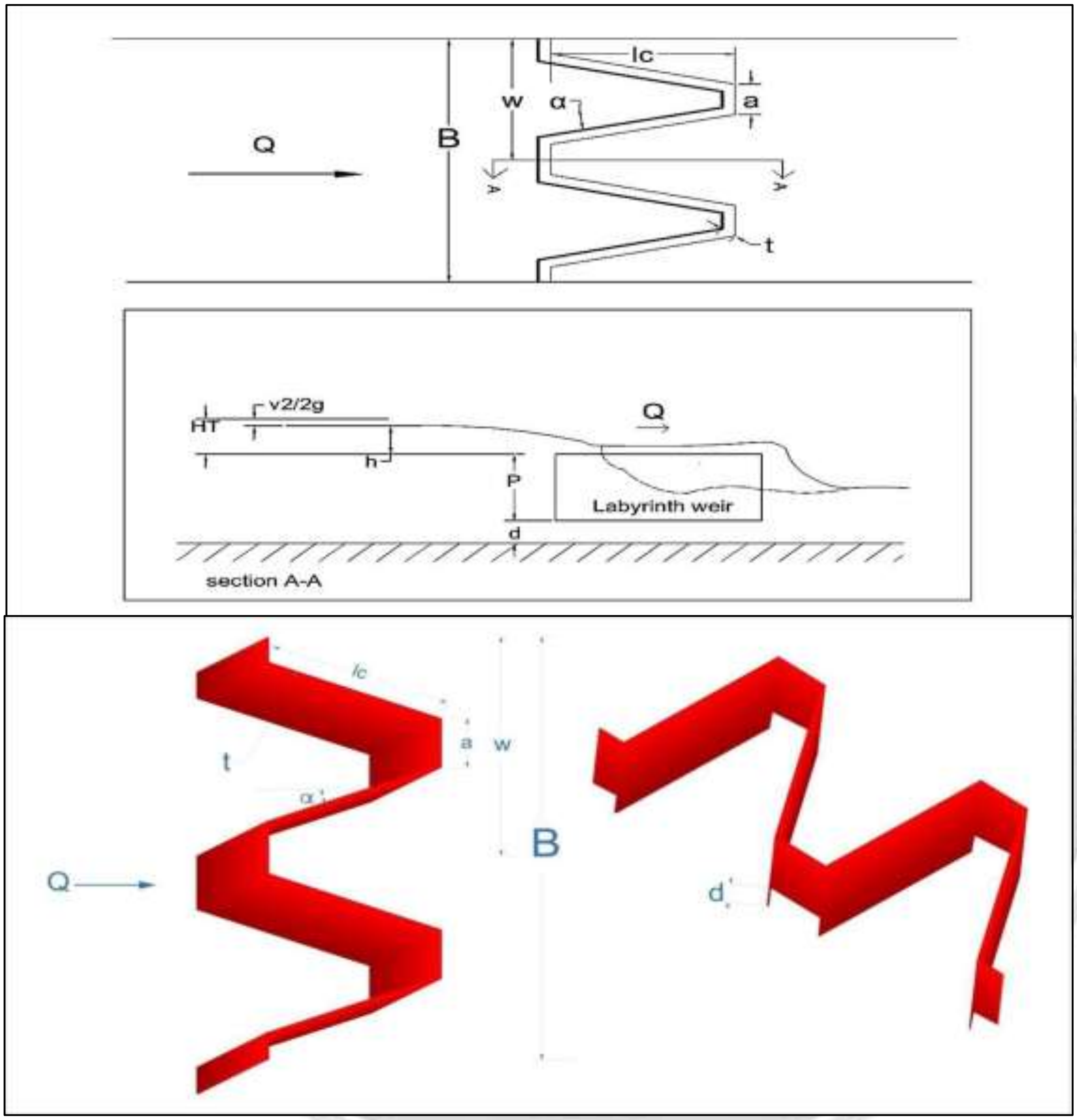

Fig. (1): Definition sketch of a top view, section, and schematic view with all dimensions of Combined Labyrinth weir-gate.

The discharge passing over the combined labyrinth weir gate depends on the geometrical and hydraulic parameters (Bijankhan and Ferro, 2017). Using Buckingham Pi-theorem and depending on the dimensional analysis of (Heydari et al., 2017), the dimensionless equation for the discharge coefficient can be written as:

$$Cd=\varphi\left(\frac{h}{P},\frac{a}{w},\frac{L}{w},\frac{w}{P},\frac{h}{d},\alpha\right) \qquad (2)$$

Where: P: Height of weir, w: width of one cycle, and α: Sidewall angle.

3. Experimental Setup AND Experiments:

The experiments were completed in the Hydraulic Laboratory of the Water Resources Department in the College of Engineering of Duhok University. The experiments were carried out in the rectangular flume with dimensions (of 0.45m height, 0.3m wide, and 5m length). An accurate point gauge is used to measure the flow profile at the centerline of the channel, and then the effective heads on the flows. Twenty-seven models of sharp-crested labyrinth weirs with gate openings are tested in the experiment with two cycles. The models are classified into three groups depending on the height of the weir (P= 15, 20, and 25 cm): one group consisting of a rectangular labyrinth weir and the other two groups of trapezoidal labyrinth weir (sidewall angle (4.67° to 19°)), with different sidewall lengths (lc), and different apex widths (a) as shown in Table (1). The rectangular gate shape is made in the apex wall and consists of 20% of the total apex wall area. The models are manufactured from Perspex sheets and the thickness of their edges is made to be 2 mm.

Table (1): Details of all models tested experimentally in the laboratory.

Model No.	Weir height P (cm)	Width of channel B (cm)	No. of cycle N	Sidewall angles α (degree)	Width of apex a (cm)	Gate height d (cm)	Sidewall length lc (cm)	L/B
1.	15, 20, and 25	30	2	Rectangular	7.5	3, 4, and 5	7.5	2
2.		30	2	Rectangular	7.5		15	3
3.		30	2	Rectangular	7.5		22.5	4
4.		30	2	12	5.5		9.72	2
5.		30	2	6.74	5.5		17.12	3
6.		30	2	4.67	5.5		24.58	4
7.		30	2	19	3.5		12.26	2
8.		30	2	11.9	3.5		19.42	3
9.		30	2	8.6	3.5		26.80	4

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4. Results AND Discussions

Logically, the amount of the total discharge over and under the labyrinth weir-gate (Q) increases with the increase of incoming flow, which is reflected as the value of the head (h). The total discharge increased by 23% and 32% when the weir height (P) increased from 15 cm to 20cm and 25cm respectively, for the same value of head (h) over the weir, this notation agrees with the findings of (Mirnaseri and Emadi, 2014) and (Jalil and Sarhan 2013), as shown in Fig. (2), for α=12°. This portion of the increase is related to the increase in gate flow.

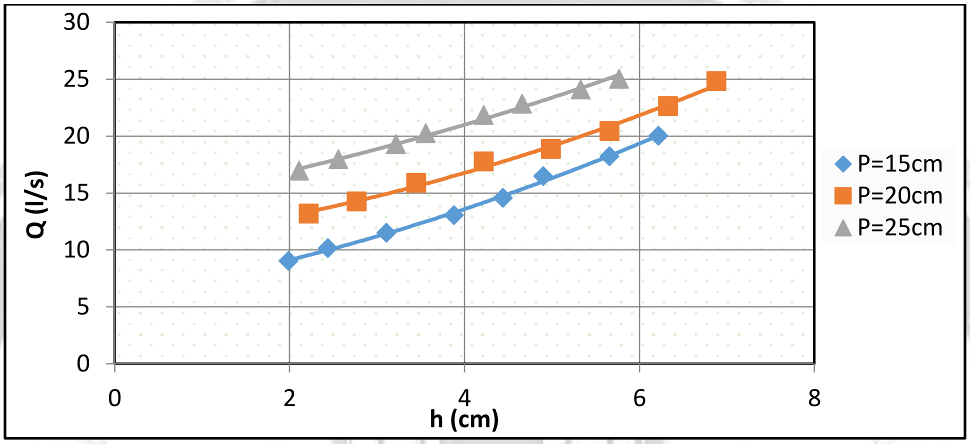

Fig. (2): Relation of Q and h for the combined labyrinth weirs.

The resulting values of the discharge coefficient (Cd) of the experimental data show decreasing values with increases in the ratio of upstream head to the height of weir (h/P) for all the models; This also agrees with (Tullis et al., 1995). Moreover, its value decreases with the increase of weir height as given in Fig. (3); this result is also proven by (Gupta et al., 2015).

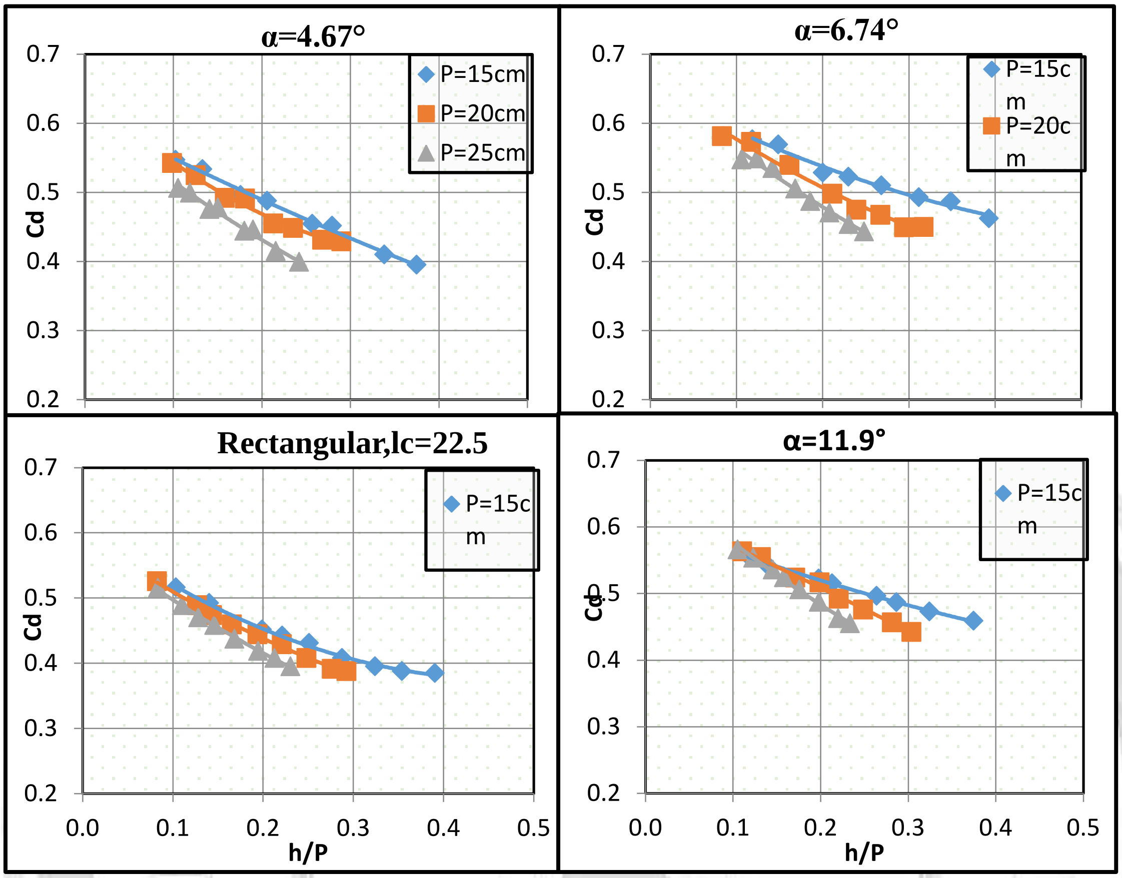

Fig. (3): Relation of the value of Cd and h/P for the combined labyrinth weirs.

5.1 Combined flow performance

The value of the discharge for the combined labyrinth weirs-gate increases with the increase in the value of the sidewall length (lc) as presented in Fig. (4), but the value of the discharge coefficient (Cd) is decreased for the same weir. When the sidewall length increases three times for the same model the discharge coefficient decreases nearly by (6-21%) as shown in Fig. (5).

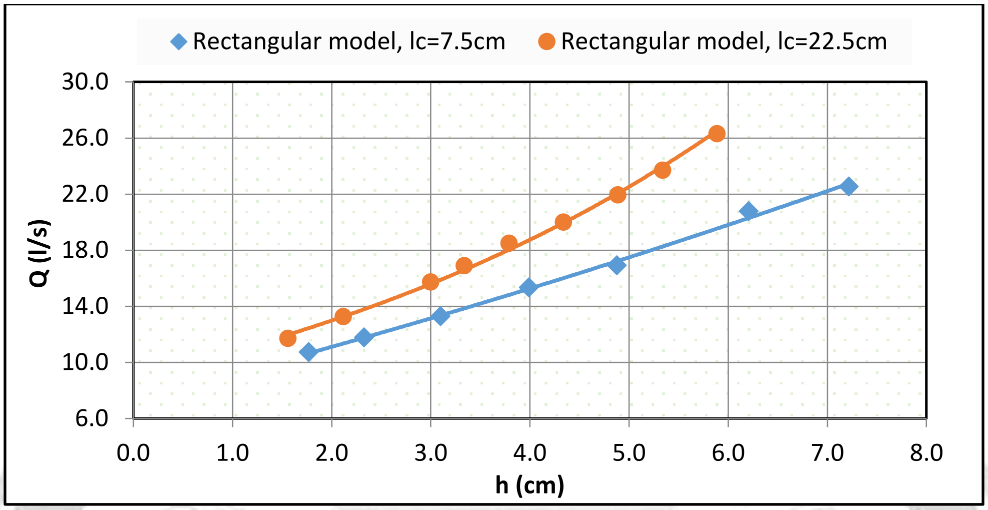

Fig. (4): Relation of Discharge (Q) and (h) for the two models of combined labyrinth weirs-gate.

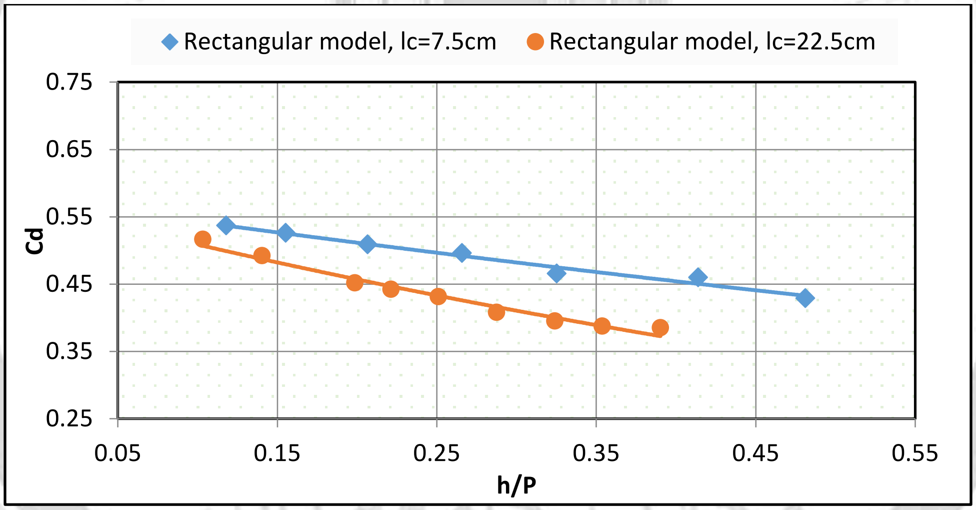

Fig.(5): Relation of the value of Cd and h/P for the two models combined labyrinth weirs-gate.

Therefore the increase in the total effective length (L) of the weir increases the value of the discharge, for comparing the rectangular combined labyrinth weir model of the present study (L=60 cm) with the combined rectangular weir model of (Jalil et al., 2018) that has (L=30 cm) for the same width of the channel, the discharge amount of the labyrinth weir is more than the combined normal weir about (10-15%) as shown in Fig. (6).

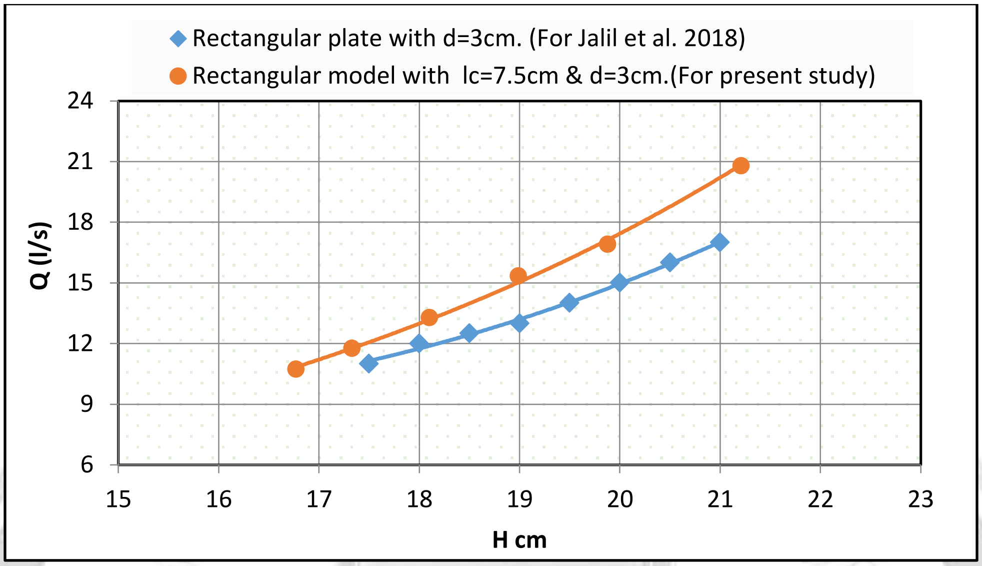

Fig. (6): Comparing the normal and Labyrinth weirs.

For the all-combined labyrinth weir-gate which has the same total length (L), the value of the discharge coefficient (Cd) of the weir is increased with an increase of the width of the apex (a) as presented in Fig. (7).

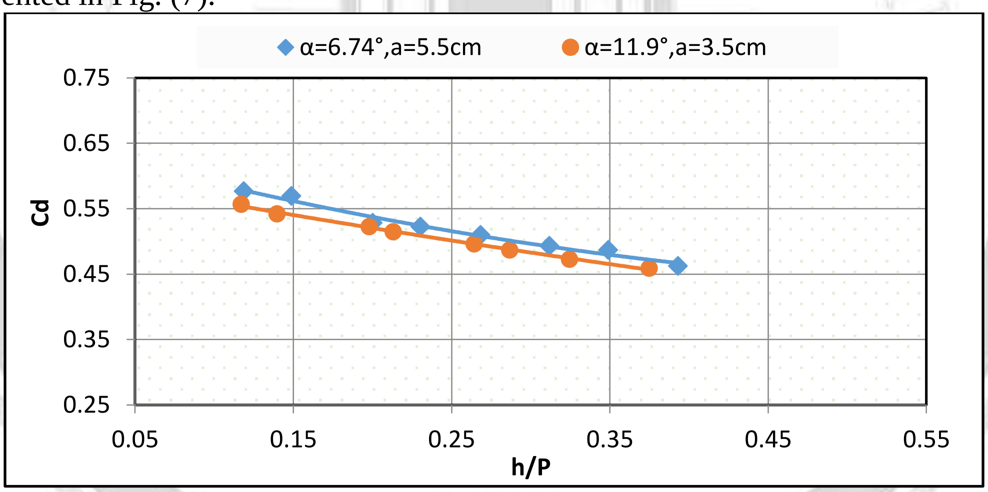

Fig. (7): Relation of the Cd and h/P for combined labyrinth weirs-gate (P=15cm).

The discharge coefficient (Cd) has a positive relationship with the sidewall angle (α) of the combined labyrinth weir as presented in Fig. (8), which displays the variation between the sidewall angles (α=11.9° and 19°). This relation is proved by Idrees et al. (2016) and also by Bilhan and Emir Emiroglu (2016).

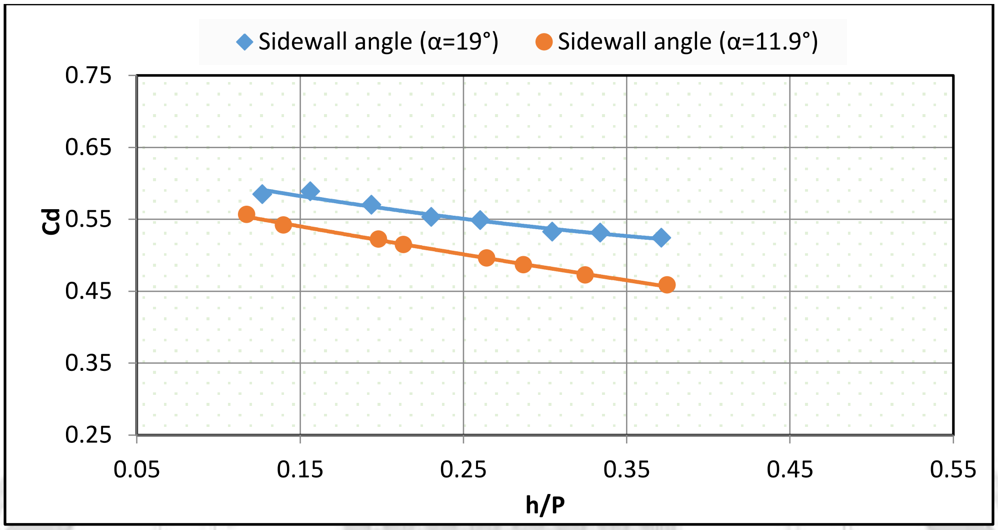

Fig. (8): Relation of the Cd and h/P for two models of combined labyrinth weirs-gate (P=15cm).

The percentage error of the value of the observed and predicted discharge coefficient (Cd) is between (-10%) and (+10%) for all models as shown in Fig. (9).

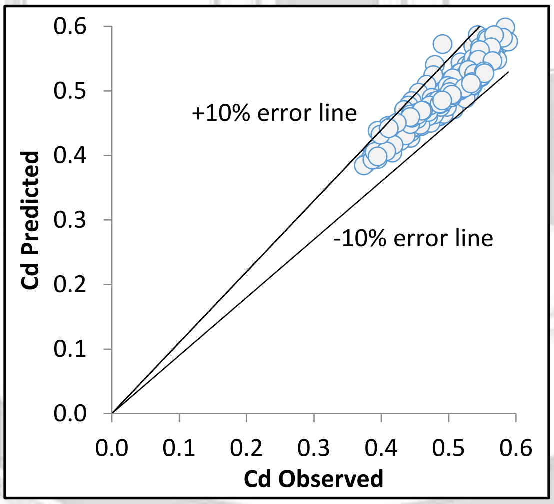

Fig. (9): Percentage error of Cd predicted for all models.

5.2 Contributions to Total Discharge

The contribution percent in the total discharge of each of the weir and the gate can be represented by the linear relation model. The model is shown in Eq. (3):

$$Q_{act} = F(Cd_g Q_{th.gate} + Cd_w\, Q_{th.weir}) \quad \ldots\ldots(3)$$

where F= interaction calculate factor (which could be a work of the geometrical structure), Cd_g and Cd_w = the percentage flow under the gate and over the weir based on their theoretical flow values respectively, $Q_{th.gate}$= theoretical discharge of the gate, and $Q_{th.weir}$= theoretical discharge of the weir.

The value of the coefficients (Cd_g and Cd_w) is calculated by linear regression with R^2=0.992 and the model presented in Eq. (4):

$$Q_{act} = F\,(0.18\, Q_{th.(gate)} + 0.38\, Q_{th.(weir)}) \quad \ldots\ldots(4)$$

The relation between the two discharges of the weir and the gate is plotted in Fig. (10), which shows that the discharge of the gate is between 40 to 60 percent of the flow over the weir due to its submergence:

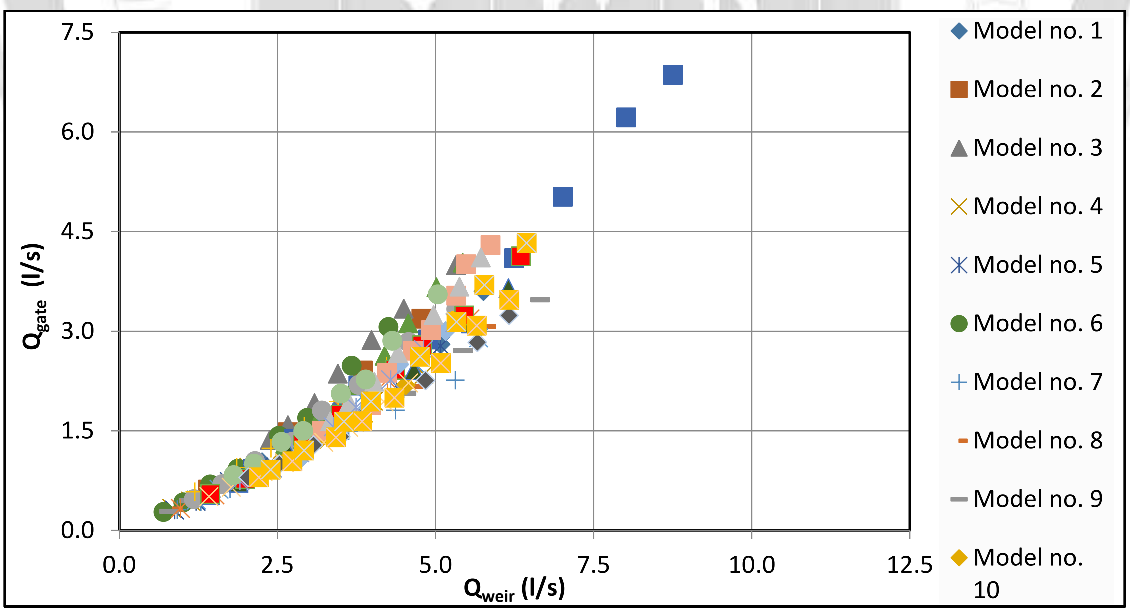

Fig. (10): Relation of the discharge of weir & gate for all models.

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The relative percentage between the two discharges (S) is affected by the height of the weir (P), weir length (L), water depth over the weir (h), and the value of the sidewall angle (α).

In combined flow, the gate is subjected to submergence due to falling water from the weir. To estimate the generated head due to the change of gate flow from free to submerge, an assumption is used to calculate the free discharge of the gate depending on the total upstream depth as if there were no weir.

The actual discharge of the gate subjected to free flow was experimentally measured so that the variation between the two actual values of the discharge of the weir and the gate (combined flow) and the actual value of the free flow of the gate was assumed to be the discharge of the weir. This variance between two amounts of discharge (Q) is assumed to be conveyed by the weir with a head of h*. The head (h*) was found to be less than that head (h) which has been formed in combined flow. Figure (11) presents the fact that the submergence of the gate has increased the head over the weir and that gives it the advantage of passing relatively more discharge for a certain incoming upstream flow. The average relative increase in the head ($\frac{h - h^*}{h^*}$) is 26% and the regression model presented in Eq. (5) with R^2 = 0.94:

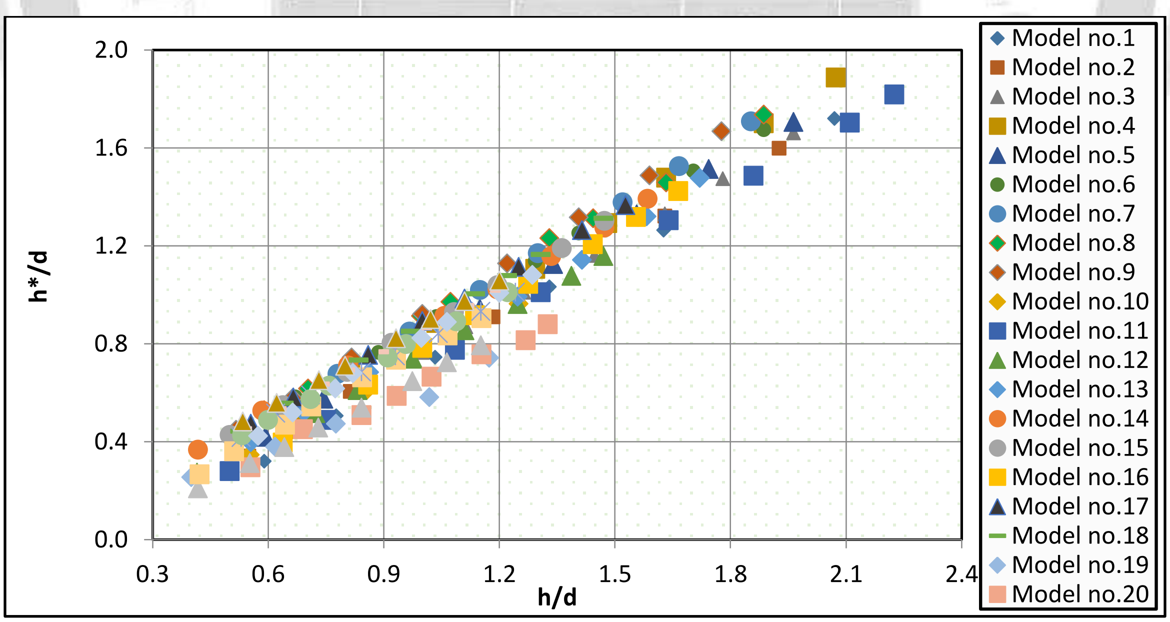

Fig. (11): Relation of h/d with h^*/d for the models.

$\frac{h^*}{d} = 0.06\frac{h}{a} + 6.22\frac{h}{B} - 0.07\alpha$ ………………………………...……….…..(5)

6. Conclusions:

The experimental investigation of the discharging capacity of the combined flow through a labyrinth weir with a gate opening at the apex wall confirmed that increasing the weir height (P) by 23% and 32% and increasing the sidewall length (lc) resulted in an increase in total discharge. The coefficient of discharge decreased as the relative head-to-weir height (h/p) increased, but increased with higher sidewall angles and apex widths. However, when the sidewall length was increased three times, the coefficient of discharge decreased by 6-21%. Additionally, the coefficient of discharge decreased with increasing sidewall length. The total effective length (L) had a positive relationship with the discharge. Using the proposed Cd equation to calculate discharge yielded values within 0.07-0.16% of the measured ones. The efficiency of the labyrinth combined structure was found to be 10-15% higher than that of the normally combined weir-gate. Discharge contribution analysis revealed that the gate discharge was 40-60% less than the weir discharge due to gate submergence, while submergence benefited the weir by increasing the head on the crest by an average of 26%.

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المساهمات الهيدروليكية في الجريان المشترك لهدارات المتاهة ذات الحافة الحادة-بوابة

رنكين شهاب محمد شاكر عبد اللطيف جليل

الخلاصة

تعمل الفتحة المستطيلة التي تشكل 20٪ من مساحة جدار القمة كبوابة داخل هدار متاهة حادة ذات دورتين ، وتقلل من تأثيرات الانغماس في المنبع ، وتسمح بمرور الرواسب. نتيجة الاستقصاء التجريبي ، ترتبط سعة تصريف المتاهة بالجريان المشترك بالأبعاد الهندسية؛ حيث تؤدي الزيادة في الجدار الجانبي وأطوال القمة إلى تقليل الغمر ، بينما يزيد التصريف (23-32٪) وعندما يزيد مستوى قمة السد بنحو (30٪). ينخفض معامل التصريف المشترك عند زيادة قيمة نسبة الرأس إلى ارتفاع السد ، كما تنخفض قيمته بنسبة (6-21٪) عند زيادة طول الجدار الجانبي 3 مرات. المعادلة المقترحة للتنبؤ بالتصريف المجمع تقع ضمن (0.07-0.16٪) من التصريف المقاس. يشير تحليل المساهمة لكل جزء من أجزاء التفريغ في هذا الهيكل إلى أن البوابة تمر (40-60٪) أقل من التفريغ من السد بسبب الغمر ؛ علاوة على ذلك ، تسبب هذه الحالة في رفع الرأس على قمة السد بنسبة (26٪) وينعكس هذا الزيادات كميزة للسد في تصريفه.

الكلمات الدالة: مساهمة الجريان، هدار المتاهة المشترك، معامل التفريغ ، تحليل الأبعاد، الانحدار الخطي.