Journal University of Zakho, Vol. 4(A) , No.1, Pp 150-158, 2016 ISSN: 2410-7549

EFFECT OF PRISMATIC SILL ON THE PERFORMANCE OF FREE FLOW UNDER SLUICE GATE

Shaker A. Jalil[1], Sarhan Abdulsatar Sarhan[2], Safa S. Ibrahim[3]
[1,2] Water Resources Engineering Department, College of Engineering, University of Duhok, Iraq
[3]Petrolum Engineering Department, College of Engineering, University of Zakho, Iraq

(Accepted for publication: May 7, 2016)

ABSTRACT:

Sills under sluice gates is used in hydraulic structures; their effect on the head generated upstream gates for certain rate of flow is related to the height and length of sill. A study is held in laboratory flume on four different prismatic sill heights and one model without sill by changing the gate opening four times for each model. Statistical analyses on the dimensionless physical quantities are done. A positive effect of sill on the performance of flow is noted by increasing the flow rate up to 25% for some models. The coefficient of discharge decreases with increase of relative sill height to the head upstream and increases with three other dimensionless parameters. The relative sill height to the gate opening shows the highest correlation factor with the discharge coefficient and its positive effect on the flow phenomena is 55.4%. Within the experimental measures limitations, a linear equation for predicting the discharge coefficient is proposed with Adj. R^2 0.923 .

Keywords: *Coefficient of discharge, Flow head, Gate opening, Sill height, Sluice gate.*

INTRODUCTION

Sluice gates are widely used to control and regulate flow rate at the crest of overflow spillways, or at the entrance of irrigation canals. The existence of gates disturbs the flow and creates non-uniform flow conditions upstream of the gate. The outflow from these gates is classified as free or submerged depending on the tail water depth. Sills located under the gates are used mainly to reduce height of the gate and consequently its weight (Alhamid, (1998)). Conclusions of many studies are widely used as a guide by the engineers in designing and operating the hydraulic structures, especially in controlling the rate of flow and water level. Many investigators were studied the hydraulic characteristics of free and submerged flow under a sluice gate without and with sills. Rajaratnam, and Humphries (1982), Clemens et al. (2003), Belaud et al. (2009), Lozano et al. (2009), Habibzadeh et al. (2011), Cassan and Belaud (2012). Swamee (1992), suggested equations for both free and submerged flows as well as criterion for submergence. Swamee et al. (2000) conducted experimental study under free and submerged flow and proposed equation for elementary discharge coefficient that can be used to compute the discharge through sluice gate having any plan shape. Junget et al. (2001), investigated widely various characteristics of a vertical sluice gate, equations for discharge coefficient, dimensionless discharge, submerged water depth, maximum allowable gate opening, and the distinguishing condition separating free flow and submerged flow were derived and plotted with consideration of flow contraction at the gate. Lin et al. (2002), presented several graphs showing the contraction coefficient against flow depths at upstream and downstream of a sluice gate. Navid and Farzin (2012), developed two equations, linear and nonlinear, to determine discharge coefficient for both free and submerged flow conditions using dimensional analysis. For free flow conditions under gates using numerical methods, the effect of gate opening (d) on coefficient of contraction (C_c) was also demonstrated by many researches such as, Fangmeier and Strelkoff (1968), Larock (1969), and Vanden-Broeck (1997). Ibrahim (2000) analyzed the experimental data of supercritical submerged flows at fixed under-gate Froude number (F_{rg}), a prediction equation was developed for the discharge coefficient (C_d) in terms of (F_{rg}) and the ratio of differential head between upstream and downstream to the gate opening ($\Delta H/d$). Neveen (2000), showed that for circular-crested sills the main factor affects the discharge coefficient was the ratio of bottom width of the sill to sill height (B/P), and the circular-crested sills have a higher discharge coefficient than the flat top sill only if (B/P) of the circular-crested sill is smaller than that of the flat top one. Clemmenset al. (2003) introduced an energy correction to account for change in (C_c) at initial submergence. The contraction coefficient under sluice gates on flat beds for both free flow and submerged conditions is studied by Gilles et al. (2009) and found that the contraction coefficient varies with the relative gate opening and the relative submergence, especially at large gate openings. Gilles also conclude that the contraction coefficient may be similar in submerged flow and free flow at small openings but not at large openings. The sill effect on characteristics of submerged flow below gates were also analyzed experimentally by many investigators.

The aim of this research is to investigate the effect of prismatic sill with different heights (different upstream and downstream slopes) under the different gate opening on the performance of free flow condition under the gate.

BACKGROUND AND EXPERIMENTAL WORK

The free flow passing gate opening is supper critical and its depth is corresponding to the gate opening. When a prismatic sill is constructed under the sluice gate, head loss will be effect by the geometrical properties due to improvement of stream lines curvature and this will cause less head (H) generated in front of gate for constant flow rate. To show the main parameters which affect the flow, figure (1) presents the definition sketch of the phenomena and the measured quantities during the experimental test. The functional relationship can be written for the actual discharge (Q_{act}) from these quantities as in equation (1).

$$Q_{act} = f_1(H, d, B, g, \rho, \mu, \sigma, P, W) \qquad (1)$$

in which H is the head, d is the gate opening, B is the channel width, g is the gravitational acceleration, ρ is the density of water, μ is the dynamic viscosity, σ is the surface tension, P is the sill height and W is the sill length.

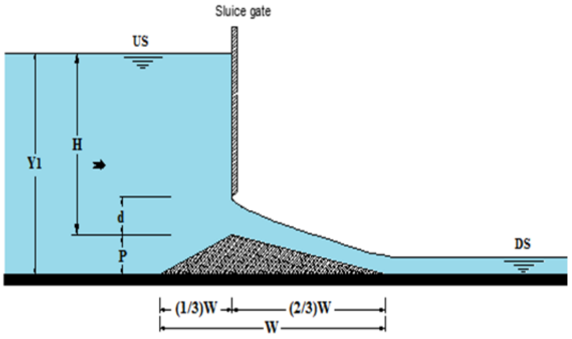


Fig. (1): Definition sketch

Equation (1) can be formed to dimensionless ratios that describe the actual discharge function as follows:

$$\frac{Q_{act}}{B.d.\sqrt{gH}} = f_2\left(\frac{P}{d}, \frac{P}{H}, \frac{P}{W}, \frac{H}{d}, R_e, W_e\right) \qquad (2)$$

The ratio between the actual discharge ($Q_{act.}$) to the theoretical value ($Q_{the.}$) is equal to the discharge coefficient (C_d) so equation (2) become:

$$\frac{Q_{act}}{Q_{the}} = f_3\left(\frac{P}{d}, \frac{P}{H}, \frac{P}{W}, \frac{H}{d}, R_e, W_e\right) \qquad (3)$$

The flow underneath the sluice gate is supercritical; the values of Reynolds number and Weber Number can be dropped. The functional relationship (3) for the coefficient of discharge (C_d) can be written as:

$$C_d = f_4\left(\frac{P}{d}, \frac{P}{H}, \frac{P}{W}, \frac{H}{d}\right) \qquad (4)$$

Froude Number regarding to gate opening (F_{rg}) which is a dimensionless parameter defending the actual flow rate under gate, it can be calculated from equation (5).

$$F_{rg} = \frac{Q_{act}}{B.d.\sqrt{gd}} \qquad (5)$$

The experimental were carried out in a horizontal flume having length 2.4 m, with rectangular cross section of 0.25 m height and 0.075 m width. The vertical sluice gate has an aluminum plate, 5 mm thick with a sharp beveled lower edge to control the upstream water depth was fixed at the crest of sill. Four models of prismatic sills, having different heights (P = 2, 3, 4 and 5 cm) with the length (W=37.3 cm), were made of Mahogany wood. The experiments were tested using five model groups. One of them without sill (P =0) and the others were prismatic sills with different height. Each model was tested with four different gate opening (d = 1.5, 2. 2.5, and 3 cm) which gives twenty models the total runs 219. The water depths were measured at the center line of the channel by point gauge verier as shown Fig. (2). The discharge was measured by two methods volumetric and calibrated rota meter. Table (1) as shown the experimental study details.

Fig. (2): The sill and sluice gate models during a test run

Table (1): Details of the experimental study

Model No.	Sill (cm)		Gate Opening d (cm)	P/W
	Height P	Length W		
1	0	37.3	1.5	0.0000
2			2.0	
3			2.5	
4			3.0	
5	2		1.5	0.0536
6			2.0	
7			2.5	
8			3.0	
9	3		1.5	0.0804
10			2.0	
11			2.5	
12			3.0	
13	4		1.5	0.1072
14			2.0	
15			2.5	
16			3.0	
17	5		1.5	0.1340
18			2.0	
19			2.5	
20			3.0	

RESULTS AND DISCUSSION

The data collected from experimental tests of the four sill height under sluice gate with one without sill is presented in Fig. (3), which shows the relation between Froude number under the gate (F_{rg}) and the dimensionless geometric parameter (H/d) for different sill height (P). It is logically clear that the head increases with increase of discharge for all gate openings (d). According to that for a certain value of flow discharge and a certain gate opining (d), the head (H) in front of the gate will be generated to satisfy the energy loss caused by the orifice (the opining between the sill and gate edge). This relation can be noted on figure (3), as Froude number (F_{rg}) present the value of flow discharge under the gate, so for a certain valve of (F_{rg}) the value of the head (H) decreases with the increase sill height. This observation leads to note that sills under sluice gate have the positive effect on the flow discharge for a certain head of flow. The relative increases in discharge is approximately between 7% to 25% for the smallest gate opening and from 3% to 14% for largest gate opening. The prismatic sills under sluice gate increase free flow performance due to the reduction of head generated in front of gate for certain discharge. This reduction caused by the gradually inlet and outlet of the sill slopes which affect curvature of stream lines.

The discharge coefficient (C_d) is evidently increases with increase of head relative to the gate opening (H/d) as presented in figure (4). Fig. (4) also shows that for a certain value of (H/d) the values of discharge coefficient have higher values for sills under gate compared with a sluice gate without sill.

The effect of gate opening for flow without sill (P = 0) and sill height equal to 4 cm is presented in Fig. (5). Fig. (5) shows the advantage of sill under sluice gate, by comparing the values of discharge coefficient (C_d) for the two models, the values are higher when there is a sill than that without sill for all four different gate opening (d).

The value of discharge coefficient (C_d) decrease with increase of the dimensionless parameter (P/H) as shown in Fig. (6) for all models, also it can see that larger gate opening create less values of (C_d), this natural behavior due to overcome certain loss that a discharge should generate it as a head to pass that rate of flow through that area. The area is the gate opening and sill height as inlet slope and out let slope.

The four geometric dimensionless parameters in equation 4 has been correlated with the dependent variable (C_d) using IBM-SPSS 20 Package. The analysis results show significant correlation between the variables,
the heights correlated parameters are (P/d, P/W, and H/d) at the 0.01 level (2-tailed) with Pearson correlation (0.804, 0.650, and 0.537) respectively, while the parameter (P/H) is correlated at the 0.05 level (2-tailed).

Linear and nonlinear regression analysis carried on to find the mathematical models between the discharge coefficient (C_d) and the independent four dimensionless geometric parameters in equation 4. The regression models were twelve different models of linear and power have achieved. To show some of the linear and nonlinear models, Table (2) present eight best models. The simplest and acceptable forms were the linear ones.

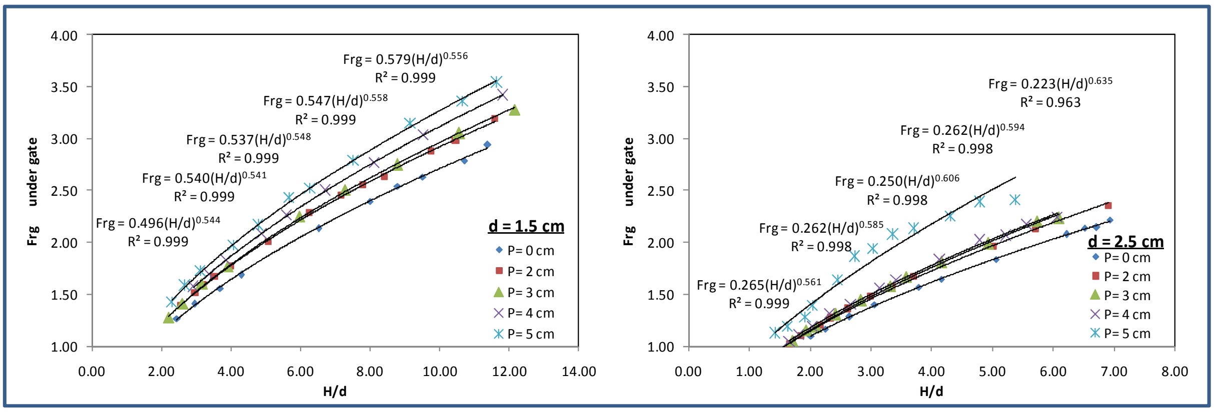


Fig. (3): Relation between Froude number under gate and dimensionless geometric parameter (H/d)

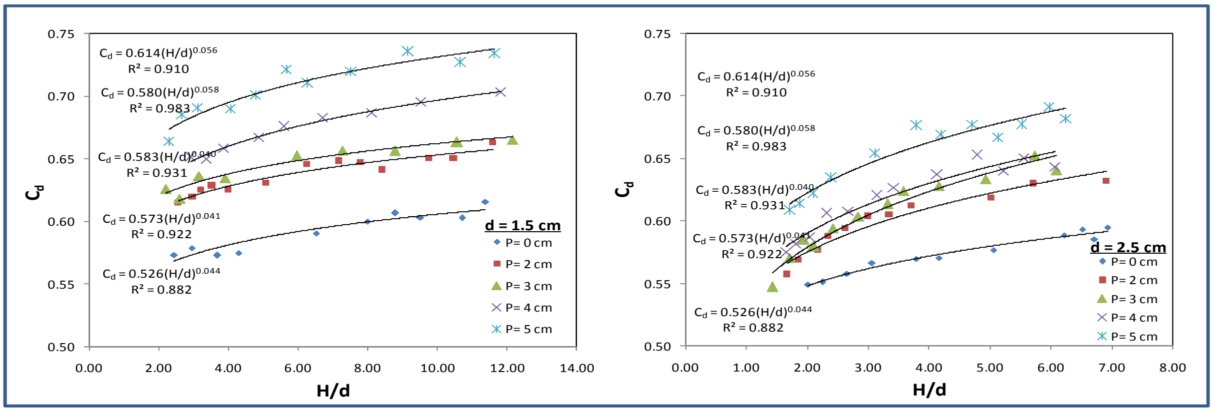


Fig. (4): Relation between discharge coefficient (c_d) and dimensionless geometric parameter (H/d)

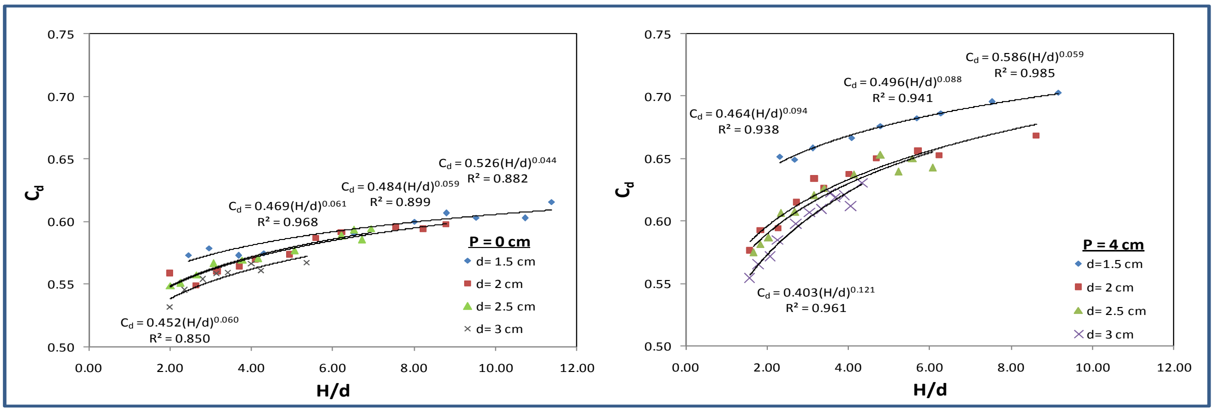


Fig. (5): Relation between discharge coefficient (C_d) and (H/d) for two models (H/d)

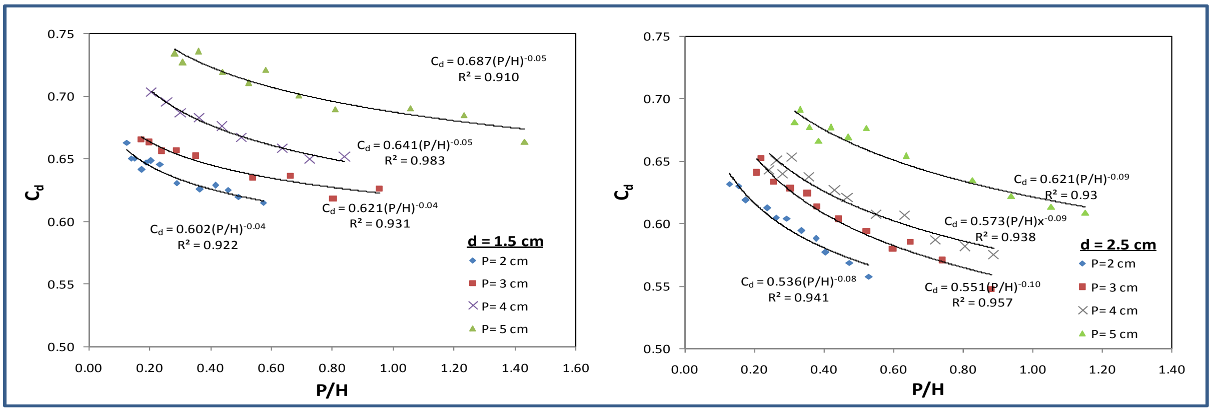


Fig. (6): Relation between discharge coefficient (C_d) and (P/H) for two gate opening

Table (2): The regression models analysis.

No.	Equation	R^2
1	$C_d = 0.549 + 0.042\frac{P}{d} - 0.069\frac{P}{H} + 0.004\frac{H}{d} + 0.268\frac{P}{W}$	0.925
2	$C_d = 0.556 + 0.053\frac{P}{d} - 0.061\frac{P}{H} + 0.004\frac{H}{d}$	0.907
3	$C_d = 0.573 + 0.061\frac{P}{d} - 0.091\frac{P}{H}$	0.888
4	$C_d = 0.567 + 0.039\frac{P}{d}$	0.647
5	$C_d = -861.381 + 0.043\left(\frac{P}{d}\right)^{0..879} - 0.32\left(\frac{P}{H}\right)^{1.205} + 861.906\left(\frac{H}{d}\right)^{0.00003883} + 16704.801\left(\frac{P}{W}\right)^{6.527}$	0.953
6	$C_d = -2.475 + \left(\frac{P}{d}\right)^{0.098} + \left(\frac{P}{H}\right)^{-0.06} + \left(\frac{H}{d}\right)^{-0.013} + \left(\frac{P}{W}\right)^{1.619}$	0.911
7	$C_d = -80.573 + 0.01\left(\frac{P}{d}\right)^2 - 0.047\left(\frac{P}{H}\right)^2 + 0.0004\left(\frac{H}{d}\right)^2 + 3.043\left(\frac{P}{W}\right)^2$	0.868
8	$C_d = -158.308 + 0.164\left(\frac{P}{d}\frac{P}{H}\frac{P}{W}\right)^{0.337} + 158.784\left(\frac{H}{d}\right)^{0.0004}$	0.900

The linear relationships between the dependant and independent variables are simplest forms. The first equation in Table (2) is found by automatic linear modelling developed in SPSS since version[19]. The automatic linear skim carried on by using Machine learing to give best predictive model (Hongwei, 2013). The output of automatic linear skim of the best fit is given in Table (3) with R^2 equal to 0.923. Equation (6) presents the relationship.

$$C_d = 0.549 + 0.042\frac{P}{d} - 0.069\frac{P}{H} + 0.004\frac{H}{d} + 0.268 \qquad (6)$$

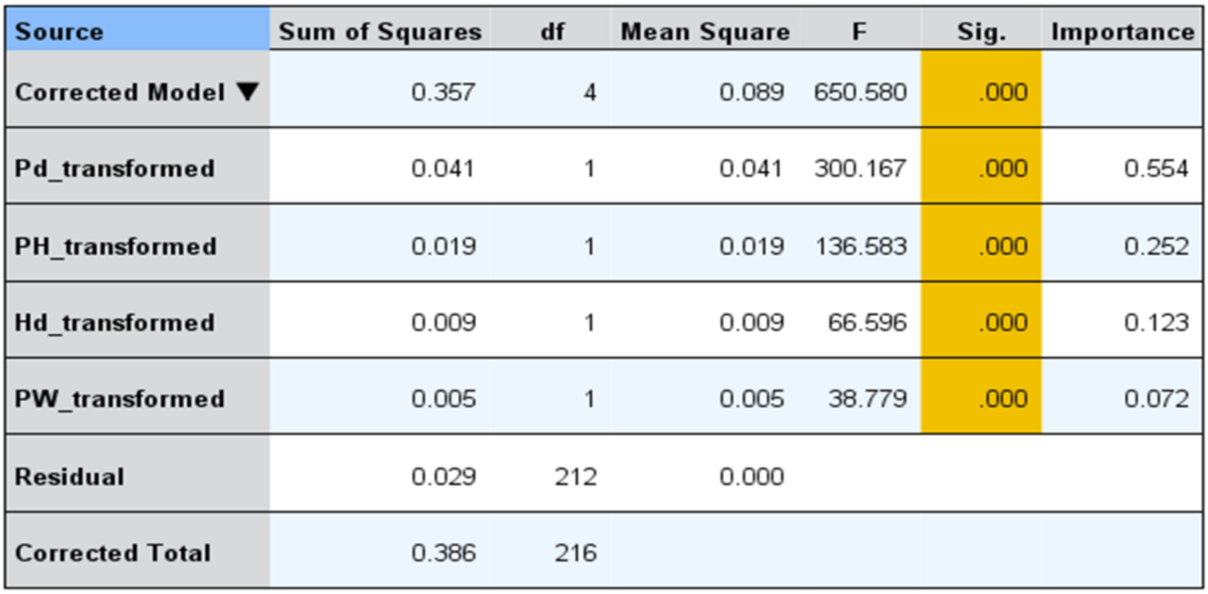
The automatic linear regression shows also the effectiveness of each dimensionless parameter on the flow phenomenon and listed it as percent importance, which leads that the parameter sill hight to the gate opening (P/d) has 55.4% on the value of (C_d), while the other parameteres in equation (5) (P/H, H/d and P/w) have (25.2%,12.3% and 7.2%, respectively). Also the trend of the effect for each dimensionless parameter on the value of (C_d) is shown in Fig. (7) which shows that the discharge coefficient decrease with the increase of (P/H) and increase with the increase of (P/d, H/d and P/W).

CONCLUSION

The performance of free flow under gate are studied experimentally and the following conclusions may forwarded.

1. The prismatic sills under sluice gate increase free flow performance relatively up to 25%.
2. The discharge coefficient increase with increase of (P/d, H/d and P/W).
3. The discharge coefficient decreases with increase (P/H).
4. Within the limitations of the present experimental work, an equation (5) for predicting (C_d) is suggested with adjusted R square more than 0.923.

Table (3): Effects target C_d, linear model



Source	Sum of Squares	df	Mean Square	F	Sig.	Importance
Corrected Model ▼	0.357	4	0.089	650.580	.000	
Pd_transformed	0.041	1	0.041	300.167	.000	0.554
PH_transformed	0.019	1	0.019	136.583	.000	0.252
Hd_transformed	0.009	1	0.009	66.596	.000	0.123
PW_transformed	0.005	1	0.005	38.779	.000	0.072
Residual	0.029	212	0.000			
Corrected Total	0.386	216				

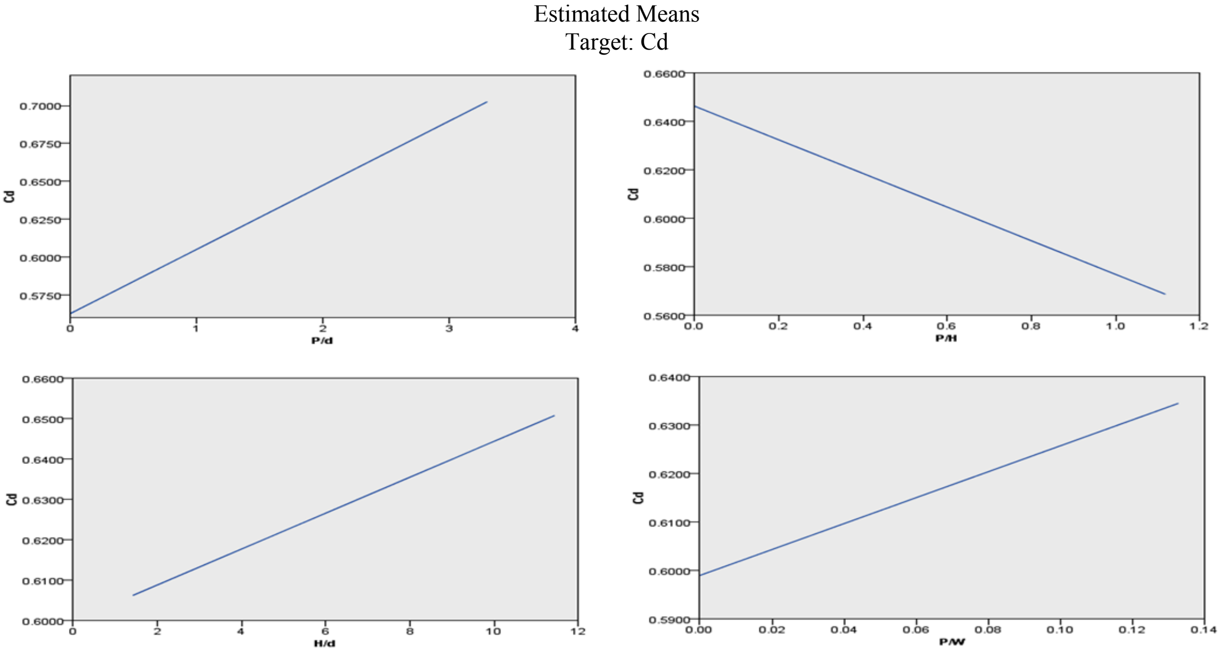


Fig. (7): Estimated means charts for the significant effects ($P<0.05$)

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کارتیکرنا دەروازایت بەلاڤوکی ل پیرابوون جریان ئازادی زێری دەرگاکەی

پوختە

بەکارئینانا دەروازیی ژێری دەرگاکەی ل بنەجهیت هایدرولیکی، کارتیکرنا درێژیا ئو بلندکرنا دەروازا ل سەر ئاستی ئاو ل پیشەی جریان تسریفا ئافی، پیرابوون خاندنك ژ چار مودیلیت دەروازا ، بلنداهیت جیاوازن هەروسا دکەل گورینا کونی دەرگاکەی چار جارا بو هەر مودیلکێ. شلوفەکرنا ژمیریاری هاتیە کارکرن ل سەر سەرەدەری فیزیایی لا بعدی، هاتیە دیارکرن کو کارتیکەری یکا باش یا دەروازا ل سەر بیرابوونا پلقێن، هەر وەسا زیدەبوونا تسریف ژ 25٪ بو هەر مودیلەکی، سەوداکرنا تسریفی کیم بت دگەل ژیادکرنا بلنداهیا دەروازا بەریژەیکی بو ئاستی سەرچاوەی و زیدەبوونا سەوەداکرنا دی، دیارکر کو رێژەی بلنداهیا ەروازا بو کونی دەرگاکەی بلنترین عاملکریدان دگەل سەوەداکرن. دیارکر کارتیکەری باش ل سەر دیاردە دەرهافیشتن 55.4٪ . ل دیف سنوری پیرابوون تاقیکردنی، هاوکیشەکا راستەهیل هاتیە پیشبینی کارکەی تسریف دکەل $R^2=0.923$

تاثير العتبة المنشورية على اداء الجريان الحر تحت البوابات

الخلاصة

تستخدم العتبات تحت البوابات في المنشات الهايدروليكية، تؤثر اطوال العتبات وارتفاعاتها على منسوب الماء في مقدمة الجريان لتصريف ماء محد.اجريت الدراسة في قناة مختبرية على اربع نماذج من العتبات مختلفة الارتفاع و نموذج بدون عتبة بواسطة تغير فتحة البوابة اربع مرات لكل نموذج تم اجراء التحليل الاحصائي على المعاملات الفيزيا ئية اللا بعدية، حيث اشارالى وجود تاثير أيجابي للعتبة على اداء التدفق وذلك بزيادة التصريف عن 25% لنفس النموذج. معامل التصريف يتناقص مع زيادة ارتفاع العتبة نسبة الى منسوب المنبع ويزيد مع المعاملات الاخرى. يظهر نسبة ارتفاع العتبة الى فتحة البوابة اعلى عامل ترابط مع معامل التصريف ويظهر تاثيره الايجابي على ظاهرة التدفق 55.4% . في حدود الاجراءات التجريبية، اقترح معادلة خطية للتنبؤ معامل التصريف مع $R^2=0.923$.