VOL. 8, NO. 4, APRIL 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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EXPERIMENTAL STUDY OF COMBINED OBLIQUE WEIR AND GATE STRUCTURE

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ABSTRACT

Flow measurement in open channel is important to support the system management. An experimental study in a laboratory flume is carried out to study flow over a sharp crested weir and under gate in combined structure as flow measurement device. Four different oblique angles to the longitudinal axis of the channel and four different heights of gate opening were used. The basic principles of statistical analysis are employed to correlate between the hydraulic and geometric dimensionless parameters with the discharge coefficient. Different relationship models with acceptable significance are suggested. It was found that the major parameters effecting significantly on discharge coefficient are (h/d, α, L/d, P/d), and value of C_d range from 0.623 to 0.403, with Standard Error 0.0047. Within the limitations of the present experimental work two different discharge equations were predicted. The first equation Which assumed that the coefficient of discharge is the same for weir and gate with R^2 of o.972, and the second which assumed that there is different percent of discharge for each weir and gate with R^2 of 0.997.

Keywords: combined structure, oblique weir and gate, gate opening, coefficient of discharge.

INTRODUCTION

The measurement of flow rates are carried on in many practical fields. Wide range of flow measuring techniques and instruments are introduced. U. S. Department of The Interior (1997) published a theoretical and experimental study for water measurement devices and their efficiency. Roger C. Baker (2000) published a handbook for nearly all the measurement devices with their equations and their calibration. Weirs of various types and shapes are one of the oldest structures used for measuring the discharge of water in open channels. Sara Bagheri *et al*. (2010) studied the curvature of nape profile theoretically as by quadratic and cubic equations together with different physical models for sharp crested weir, they introduced that the coefficient of discharge and simulate flow profile reasonable between them. Shesha Prakash *et al*. (2011) investigated the flow over inclined rectangular weir with angles 0˚ 15˚, 30˚, 45˚, 60˚, they had found that the discharge over the weir increases with the increase in inclination; they introduced a single head-discharge-inclination equation which can be used for any rectangular weir of any desired inclination. Gates also have been used as a flow meter for controlling and measuring irrigation flows for many years ago. Jung-Fu Yen *et al*. (2001) investigated characteristics of vertical sluice gate and predict equations for discharge coefficient and dimensionless discharge, they conclude that better accuracy for flow conditions can be achieved by appropriate contraction coefficient for the gate which has significant effects on the hydraulic characteristics of the gate, the study was for free and submerged water depth. The energy loss due the contraction of cross section was used as flow meters by Aldabakh A. J. and Jumaa E. A. (2007), they used a portable devices as a sharp pier fixed in the middle of rectangular channel, the change in the flow profile due to the pier prism in flow was used to create a relationship between the coefficient of discharge and Froude number for free flow.

Bahzad and Tahseen (2005) studied the characteristics of free flow over normal and oblique weirs with semi circular crests, they found that the value of Cd increase as values of head to crest height ratio increase for normal weirs, and Cd increase as the ratio decrease for oblique weirs. Nguyen Ba Tuyen (2006) carried experimental study on oblique weir with angles of 0˚, 45˚ and 60˚, his study shows the relation between energy loss and the discharge coefficient, he has analyzed the velocity components vertically and horizontally for a reasonable distance upstream and downstream using simulation, then he compared between the experimental and theoretical investigation, and related the coefficient of discharge to the geometric parameter, also Nguyen Ba Tuyen (2007) studied experimentally flow over oblique weir the analysis of his data which was collected from acoustic (ADV) and electro-magnetic (EMF) single point velocimeters and depth measurements, he found that the coefficient of discharge slightly decrease with increasing oblique angle, and increase with increasing discharge capacity .

Combining weir and gates in one structure may reduce effect of sediments and floating materials upstream and may affect scoring downstream. The performance of the combination has been studied by many researchers. Abdel-Azim, at (2001) studied the combined flow over shape rectangular weir and rectangular gate experimentally they found empirical dimensionless relationship for the coefficient of discharge with three dimensionless geometric parameters they find also that there is no effect on flow when the opening isn't very narrow. Abdel-Azim *et al*. (2002) carried experimental investigation on combined measurement device of rectangular weir and rectangular gate, they predict non dimensional equation for the discharge through this device for horizontal and sloping channel, the investigation

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conclude that the major geometric parameters effects the discharge value are the H/d (depth of flow upstream to the gate opening) and y/d (the distance between the weir and the gate to the gate opening). Kassem Salah El-Alfy (2005) studied experimentally the effect of streamlines curvature on discharge coefficient due the height of the weir his investigation include of four different types of weirs, he introduced relationships between discharge coefficient, C_d and the relative head, H/Y for these weirs. Hayawi H. A. M. *et al*. (2009) investigated the coefficient of discharge for a combined hydraulic measuring device of rectangular weir and semi-circular gate, their results show that C_d increase as the value of head over to the diameter of gate increase. Hayawi H. A. M. *et al*. (2008) their investigation was to find the characteristics of free flow through the combined triangular weir and a rectangular gate. They found that the theoretical discharge is inversely proportional to the geometrical dimensionless parameters and directly to distance between the bottom of the weir and the upper edge of the gate.

In this investigation the characteristics of combined flow over weir and under gate was studied in open channel as a device for controlling the flow. A plate of transparent plastic was used with different angles oblique to the flow direction together with different gate opening from the bed of the channel

THEORETICAL BACKGROUND

The flow toward the combined structure of weir and gate is a fall over weir and flow through the gate, the two discharges capacity are depending on the depth of water in the channel upstream of the combined structure, Figure-1 shows the definition sketch for the flow with the geometric parameters. To compute the discharge through combined structure the equations of the flow over a weir can be added to the equation of the gate assuming one coefficient of discharge (C_d) for the overall structure.

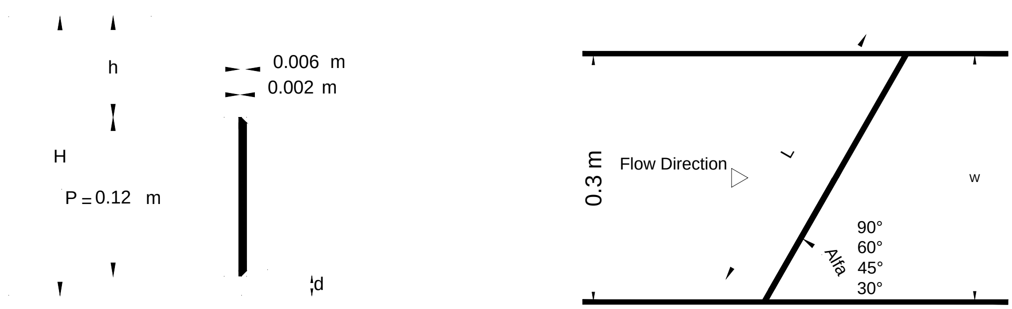

Figure-1. Definition sketch for the investigation.

$$Q_{th} = Q_{gate} + Q_{weir} \quad (1)$$

$$Q_{th} = L \cdot d\sqrt{2gH} + \frac{2}{3}\sqrt{2g}L \cdot h^{3/2} \cdot \quad (2)$$

Where

Q_{th} = discharge passing over the weir and under gate (L^3 /T)
Q_{weir} = discharge passing over the weir (L^3 /T)
Q_{gate} = discharge passing under gate (L^3 /T)
H = upstream head (L) = h + P + d
d= height of the gate opening (L)
h= head depth of water over the weir (L)
P= vertical distance between the lower edge of the weir and the upper edge of the gate opening (L)
L = weir length (L)
g = acceleration of gravity (L/T^2)

The actual discharge of total structure can be written using one coefficient of discharge as follows:

$$Q_{act} = C_d\left[L \cdot d\sqrt{2gH} + \frac{2}{3}\sqrt{2g}L \cdot h^{3/2} \cdot\right] \quad (3)$$

Where

C_d = coefficient of discharge

Based on Eq. (3) and using dimensional analysis, the following functional relationship can be obtained.

$$C_d = f\left(\frac{H}{d}, \frac{h}{d}, \frac{P}{d}, \frac{h}{L}, \frac{L}{d}, \frac{P}{h}, \alpha, R_e, W_e\right) \quad (4)$$

Where

α = oblique angle from the direction of flow in degrees.
R_e = Reynolds number
W_e = Weber Number

The values of Reynolds number and Weber number are not affected due to turbulent flow and neglecting surface tension. The angle α can be replaced by the ratio of L/W which is the length of the weir to the channel width.

EXPERIMENTAL WORK

The experimental investigation was carried out in a horizontal flume of working length 5m, having a

VOL. 8, NO. 4, APRIL 2013 ISSN 1819-6608
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rectangular cross section of 0.45m height and 0.3m width. Accurate point gauge with venier scale reading to 0.1* 10^{-3} m was used for measurements of flow profile head upstream at center line of flume each 5 cm. A plate of 0.006 m thickness of transparent plastic was used to construct four weir models of 0.12m height and lengths adequate to the oblique angles. The weir was sharpened to 0.002m from the upper and lower sides. Figure-2 shows photo for the flow over and through the combined structure.

Figure-2. Representation of the combined structure.

The height of the gate opening was 0.02, 0.03, 0.04 and 0.05m for each of the four angle, so sixteen different models was tested. The models were classified into four groups depending on the value of oblique angle Table-1 shows the groups.

Table-1. Details of the model tested.

Group	Model No.	depth **d** (cm)	Crest length **L** (cm)	L/d	L/W	L/P
A α = 90º	1	2	30	15	1	2.5
	2	3	30	10	1	2.5
	3	4	30	7.5	1	2.5
	4	5	30	6	1	2.5
B α = 60º	5	2	34.6	17.3	1.2	2.9
	6	3	34.6	11.5	1.2	2.9
	7	4	34.6	8.7	1.2	2.9
	8	5	34.6	6.9	1.2	2.9
C α = 45º	9	2	42.4	21.2	1.4	3.5
	10	3	42.4	14.1	1.4	3.5
	11	4	42.4	10.6	1.4	3.5
	12	5	42.4	8.5	1.4	3.5
D α = 30º	13	2	60	30	2	5
	14	3	60	20	2	5
	15	4	60	15	2	5
	16	5	60	12	2	5

RESULTS AND DISCUSSIONS

The data collected from the tests of the four angle group and four heights of gate opening models are presented in Figures 3 to 6. It is clear that the discharge passing the combined structure is increases with increase of the upstream head (H) and with increase of the gate height opening and also the discharge increases with decrease of the angle (α), which means a longer length of weir and gate. The increase of the discharge capacity of the other geometrical parameters for certain upstream depth is reasonable.

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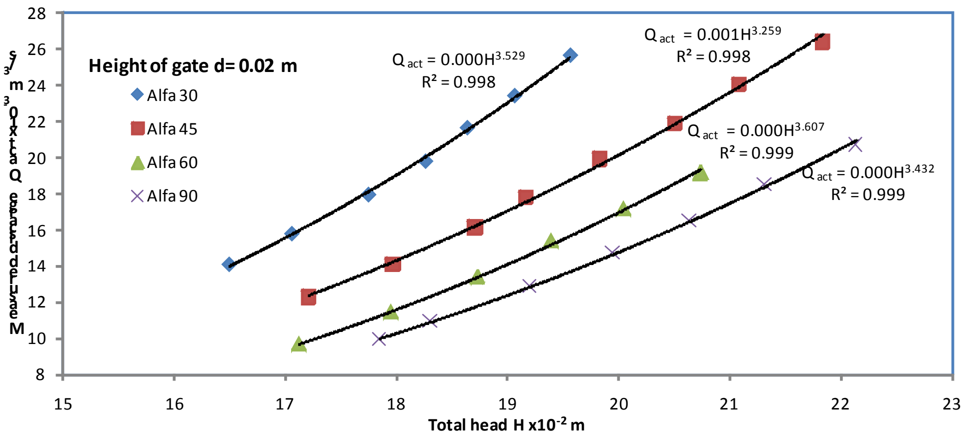

Figure-3. Relation between the discharge and upstream head for d =0.02 m.

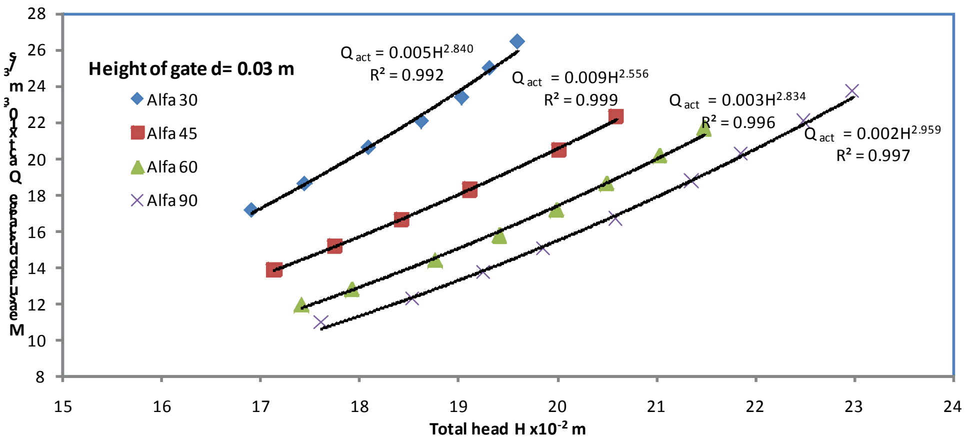

Figure-4. Relation between the discharge and upstream head for d = 0.03m.

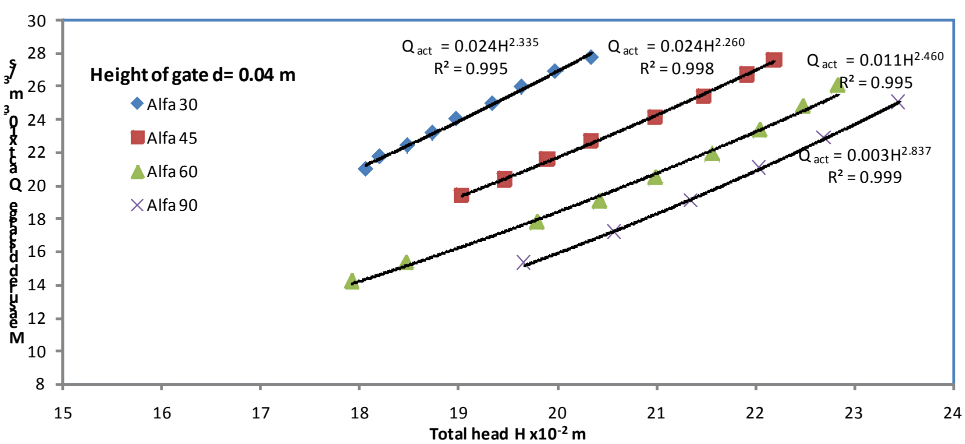

Figure-5. Relation between the discharge and upstream head for d = 0.04m.

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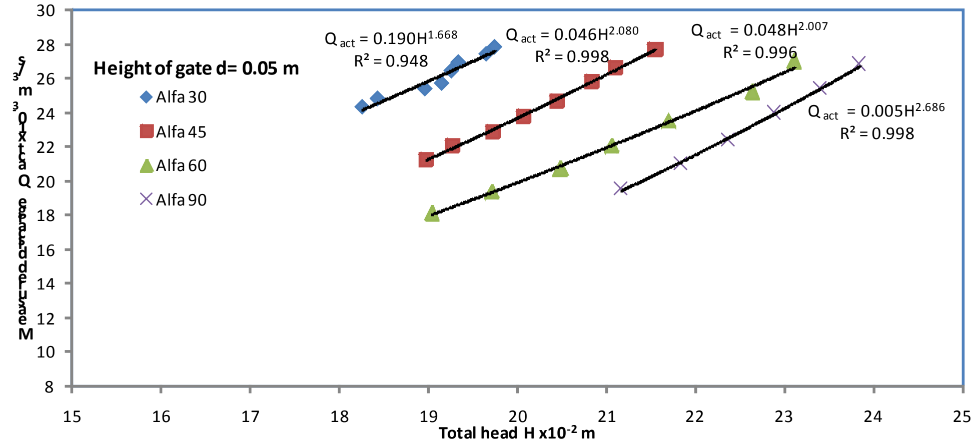
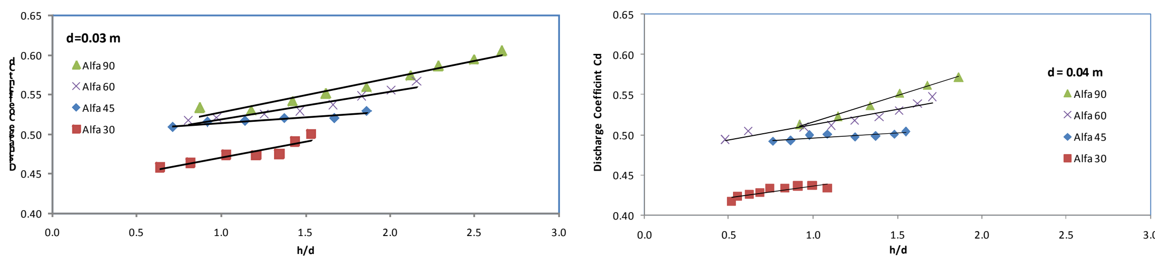


Figure-6. Relation between the discharge and upstream head for d = 0.05m.

The reasonable power relationship shown in Figures 3 to 6 between the measured discharge and the upstream head (H) of the form $Q=K H^n$, the power (n) has a certain trend of decreasing value with increase of height opening of the gate (d), the constant (K) has the increasing trend values with increasing value of (d), to explain this trend of increasing values is due the increasing discharge capacity passing through the gate. It can be also mentioned that all the equations with a high coefficient of determination.

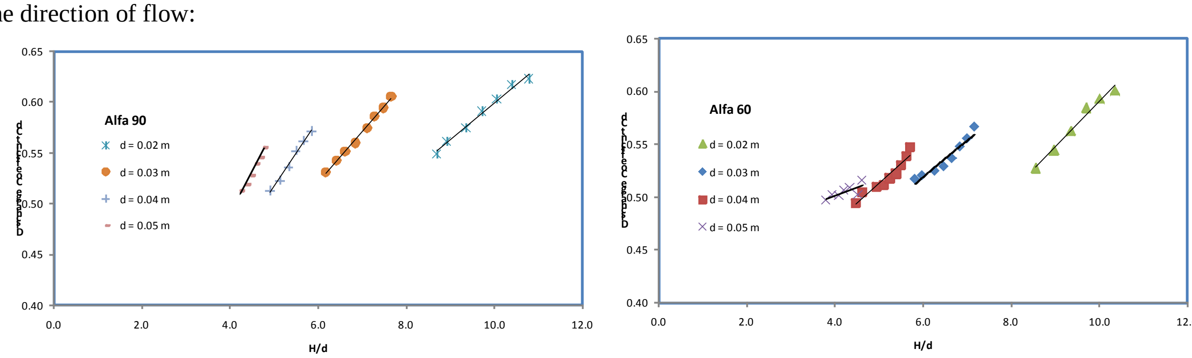
The calculated value of discharge coefficient C_d in equation (3) was studied with the dimensionless parameters in equation (4) it is clear that the value of C_d increases with the increase of h/d and decreases with the decrease of oblique angle from the direction of flow, Figure-7 shows the relation.



(a) (b)

Figure-7. Relation between the discharge coefficient and h/d.

The value of C_d increase with increase of H/d Figure-8 shows the tendency for different values of oblique angle to the direction of flow:



(a) (b)

Figure-8. Relation between discharge coefficient and H/d.

It also found that the value of C_d decreases with increases of (P/h) and (L/h) as shown in Figures 9 and 10. The decreases of C_d are due to decrease of head acting on the weir causing less performances of weir relative to the gate flow:

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ARPN Journal of Engineering and Applied Sciences

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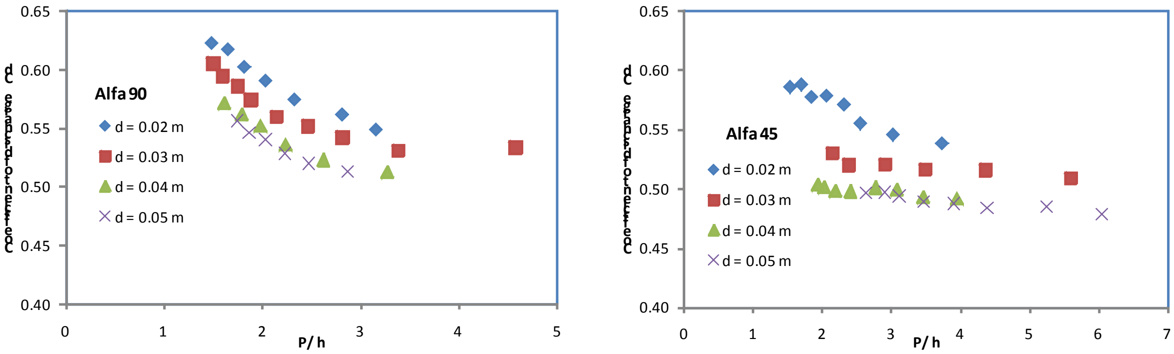
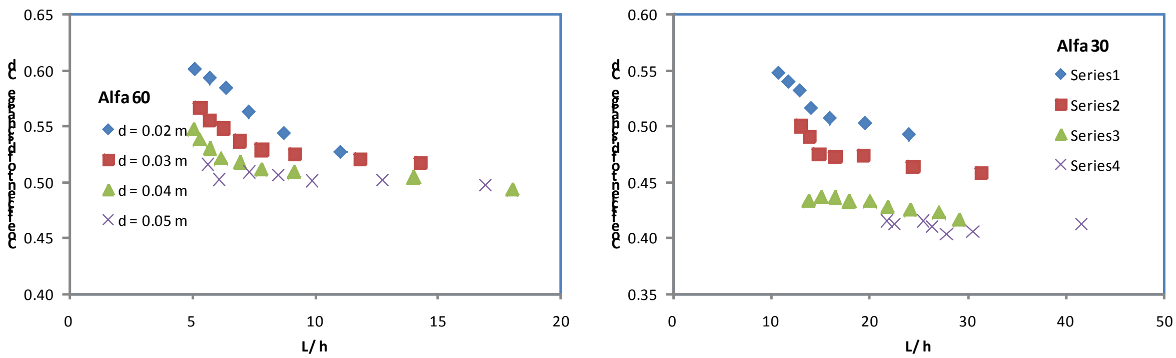


(a) (b)

Figure-9. Relation between discharge coefficient and P/h.



(a) (b)

Figure-10. Relation between discharge coefficient and L/h.

The coefficient of discharge for weir is heigher than that for a gate due to the contraction under the gate, that fact effects also the conbined stucture causing better performance of the flow over the wier than that under the gate. To find the mathematical relation of the coefficient of discharge C_d with other dimensionless parameters, the value of discharge coefficient C_d were in the range from 0.623 to 0.403, With Standard Error 0.0047 and Standard Deviation 0.051. The total experimatal measures of four oblique angles, four heights of gate openings and the calculated values of the dimensionless parameters of the equation (4) were combinrd to carry stastical analysis for the data by using the fasilites of the SPSS 17 Package. The correlation between the depentent variable Cd with the calculated dimiensionless parameters was studidet, it was found that the indepentednt parametres (H/d, h/d, P/d, P/h, L/h, L/d and L/W) have a significant correlation at the 0.01 level (2- tailed) and the highest positve Pearson Correlationis factor 0.828 between the C_d and h/d.

Nonlinear Regression Analysis of 26 different models is carried on by the same package. The models were defined in three equation types, the linear, square and power. The best 9 models obtained from different relationships analysis of the dimensionless parameters with the highest R^2 are shown in Table-2.

Table-2. The regression models analysis.

No.	Equation	R^2
1	$Cd = 0.639 + 0.033\frac{h}{d} - 0.138\frac{L}{W} + 0.007\frac{L}{d} - 0.018\frac{P}{d}$	0.972
2	$Cd = 0.565 + 0.011\frac{H}{d} + 0.098\frac{h}{d} - 0.010\frac{P}{d} - 0.007\frac{P}{h} + 0.000062\frac{L}{h} - 0.075\frac{L}{W}$	0.944
3	$Cd = 0.595 + 0.076\frac{h}{d} + 0.074\frac{P}{d} - 0.083\frac{L}{W}$	0.915
4	$Cd = 0.504 + 0.005\left(\frac{H}{d}\right)^2 - 0.013\left(\frac{h}{d}\right)^2 - 0.007\left(\frac{P}{d}\right)^2 - 0.0002\left(\frac{P}{h}\right)^2 - 0.000004\left(\frac{L}{h}\right)^2 - 0.024\left(\frac{L}{W}\right)^2$	0.935
5	$Cd = 0.562 + 0.007\left(\frac{h}{d}\right)^2 - 0.039\left(\frac{L}{W}\right)^2 + 0.0001\left(\frac{L}{d}\right)^2 - 0.001\left(\frac{P}{d}\right)^2$	0.946
6	$Cd = 0.558 + 0.006\left(\frac{h}{d}\right)^2 - 0.035\left(\frac{L}{W}\right)^2$	0.951
7	$Cd = 0.219\left(\frac{H}{d}\right)^{0.44}\left(\frac{h}{d}\right)^{-0.855}\left(\frac{P}{d}\right)^{0.425}\left(\frac{P}{h}\right)^{-1.125}\left(\frac{L}{h}\right)^{0.266}\left(\frac{L}{d}\right)^{0.198}\left(\frac{L}{W}\right)^{-0.663}$	0.940
8	$Cd = 2.536\left(\frac{H}{d}\right)^{0.440}\left(\frac{P}{d}\right)^{-0.233}\left(\frac{P}{h}\right)^{2.203}\left(\frac{L}{h}\right)^{-2.207}\left(\frac{L}{W}\right)^{2.008}$	0.940
9	$Cd = 0.331\left(\frac{H}{d}\right)^{0.455}\left(\frac{P}{d}\right)^{-0.245}\left(\frac{L}{W}\right)^{-0.199}$	0.940

The best and simplest equation for predecting the value of discharge coefficient C_d is the first one in the Table-2, which has been found by the regression of the data of C_d assusieted with 7 dimensionsless parameters using stepwise method of including independent varables in modele to determing statisticaly signifucnce pridictors in the equation by starting the modele with the higher indepent correlation varaible in the matrix at confidence level of 95% while after including four indepentent varibles and stopped with Adjusted R square is 0.971 and stadard Error of estimate equle to 0.0087664.

$$Cd = 0.639 + 0.033\frac{h}{d} - 0.138\frac{L}{W} + 0.007\frac{L}{d} - 0.018\frac{P}{d} \qquad (5)$$

The statistical analysis output details for the proposed equation (5) are shown in Table-3 and Table-4. The plot of the normal P-P regression standardized residual is shown on Figure-11.

Table-3. Stepwise regression analysis.

Model Summary[e]

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.828[a]	.685	.682	.0290004	
2	.968[b]	.938	.937	.0129615	
3	.980[c]	.960	.959	.0103980	
4	.986[d]	.972	.971	.0087664	.728

a. Predictors: (Constant), h/d
b. Predictors: (Constant), h/d, L/W
c. Predictors: (Constant), h/d, L/W, L/d
d. Predictors: (Constant), h/d, L/W, L/d, P/d
e. Dependent Variable: Cd=Qm/Qt

ANOVA[e]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	.214	1	.214	254.350	.000[a]
	Residual	.098	117	.001		
	Total	.312	118			
2	Regression	.293	2	.146	871.505	.000[b]
	Residual	.019	116	.000		
	Total	.312	118			
3	Regression	.300	3	.100	924.552	.000[c]
	Residual	.012	115	.000		
	Total	.312	118			
4	Regression	.304	4	.076	987.498	.000[c]
	Residual	.009	114	.000		
	Total	.312	118			

a. Predictors: (Constant), h/d
b. Predictors: (Constant), h/d, L/W
c. Predictors: (Constant), h/d, L/W, L/d
d. Predictors: (Constant), h/d, L/W, L/d, P/d
e. Dependent Variable: Cd=Qm/Qt

Table-4. Stepwise regression coefficients.

Coefficients[a]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	Upper Bound
1	(Constant)	.441	.005		83.326	.000	.431	.452
	h/d	.050	.003	.828	15.948	.000	.044	.057
2	(Constant)	.555	.006		96.534	.000	.544	.566
	h/d	.041	.001	.665	27.298	.000	.038	.043
	L/W	-.071	.003	-.528	-21.673	.000	-.077	-.064
3	(Constant)	.583	.006		100.542	.000	.572	.595
	h/d	.028	.002	.462	14.509	.000	.024	.032
	L/W	-.103	.005	-.767	-21.653	.000	-.112	-.093
	L/d	.003	.000	.302	8.078	.000	.002	.003
4	(Constant)	.639	.009		67.692	.000	.621	.658
	h/d	.033	.002	.542	18.541	.000	.029	.037
	L/W	-.138	.006	-1.029	-21.324	.000	-.150	-.125
	L/d	.007	.001	.772	10.298	.000	.005	.008
	P/d	-.018	.003	-.457	-6.913	.000	-.023	-.013

a. Dependent Variable: Cd=Qm/Qt

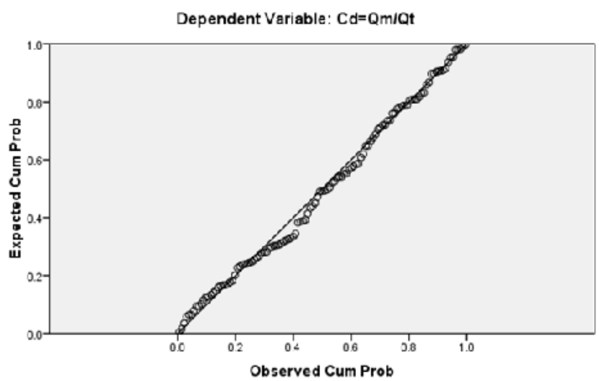


Figure-11. Normal P-P plot regression standardized residual.

The sugested above equation (5) assummed that the coefficient of dicharge is the same for the weir and the gate in the combined structure, while each one performs depending on its phenomena of flow. To find percent of flow over weir and under gate, a linaer regression analysis was caried for the actual measured discharge as dependent variable and the thoretical calculated dicharges over the weir and under the gate as independent variables. The model of the relation is pesented in equation (6).

$$Q_{measured} = C_g \cdot Q_{Tho.gate} + C_w \cdot Q_{Tho.weir} \quad (6)$$

Where

C_g= percent of theoretical flow under gate
C_w= percent of theoretical flow over weir

The output of the model analysis for the range of experimatal measrements shown in Table-5 and Table-6.

Table-5 (a). The regression models analysis for equation (6).

Model Summary[c,d]

Model	R	R Square[b]	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.998[a]	.997	.997	1.1941686	.365

a. Predictors: Q-weir, Q- gat

b. For regression through the origin (the no-intercept model), R Square measures the proportion of the variability in the dependent variable about the origin explained by regression. This CANNOT be compared to R Square for models which include an intercept.

c. Dependent Variable: Qmear

d. Linear Regression through the Origin

ANOVA[c,d]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	52233.654	2	26116.827	18314.219	.000[a]
	Residual	166.847	117	1.426		
	Total	52400.501[b]	119			

a. Predictors: Q-weir, Q- gat

b. This total sum of squares is not corrected for the constant because the constant is zero for regression through the origin.

c. Dependent Variable: Qmear

d. Linear Regression through the Origin

Table-5 (b) Coefficients for models in equation (6).

Coefficients[a,b]

Model		Unstandardized Coefficients B	Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	Upper Bound	Collinearity Statistics Tolerance	VIF
1	Q- gat	.403	.005	.613	73.331	.000	.392	.414	.389	2.572
	Q-weir	.754	.014	.443	52.911	.000	.726	.782	.389	2.572

a. Dependent Variable: Qmear

b. Linear Regression through the Origin

VOL. 8, NO. 4, APRIL 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

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The analysis lieds to form equation (7) between the flow of weir and flow under the gate.

$$Q_{measured} = 0.403 \cdot Q_{Tho.gate} + 0.754 \cdot Q_{Tho.weir} \qquad (7)$$

Comparing the calculated values of the discharge from the two segusted equations (5) and (7) it clear that equation (7) has predicted more scattering values than equation (5), see Figure-12, Using statistical descriptive analysis which shown in Table-6 for percent error calculated relative the measured discharge. From Table-6 the mean percent error 0.03 with stabdard error of 0.154 in equation (5) and 1.459 mean percent error in equation (7) with atanderd error of 0.488 that mean eqution (5) is more confidence to predicte the dischargein the combined structure.

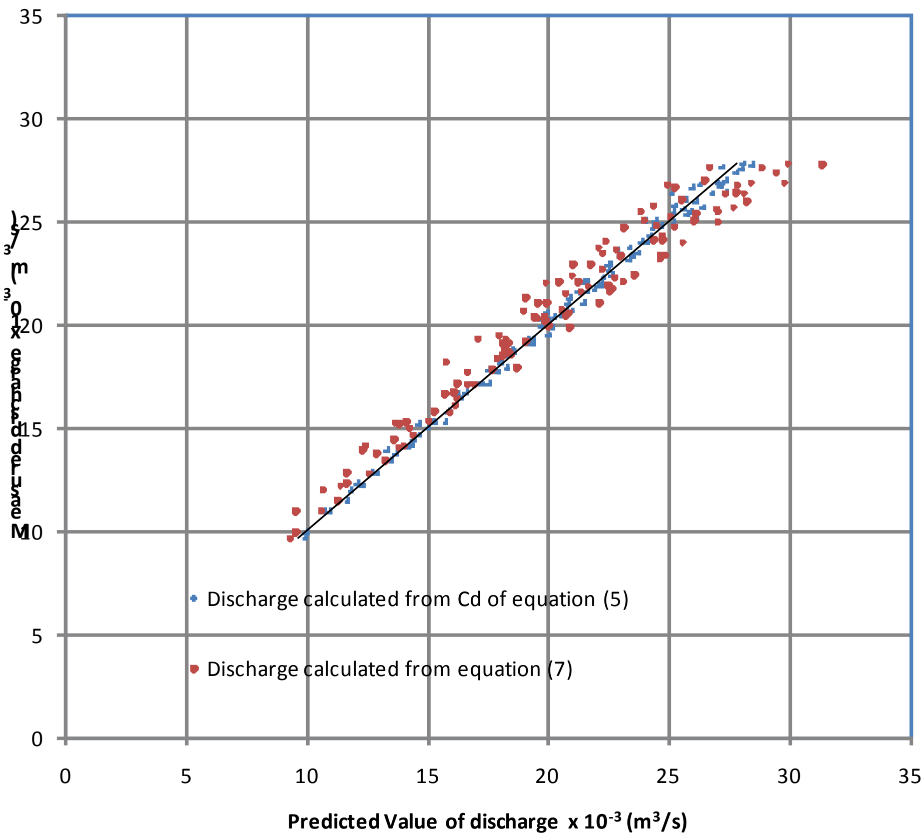

Figure-12. Comparison between measured and calculated discharge.

Table-6. Descriptive analysis or error in the proposed equations.

Error % in Equ.(5)		*Error % in Equ.(7)*	
Mean	-0.030565392	Mean	1.459114
Standard Error	0.154663671	Standard Error	0.488033
Median	-0.036369837	Median	1.682439
Standard Deviation	1.687181467	Standard Deviation	5.323809
Sample Variance	2.846581302	Sample Variance	28.34294
Kurtosis	-0.114304391	Kurtosis	-0.66915
Skewness	0.263401481	Skewness	-0.16699
Range	8.739196522	Range	22.48266
Minimum	-3.86426555	Minimum	-10.5863
Maximum	4.874930972	Maximum	11.89634
Sum	-3.637281657	Sum	173.6346
Count	119	Count	119
Confidence Level(95.0%)	0.306276173	Confidence Level(95.0%)	0.966438

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CONCLUSIONS

The flow over weir and under gate in combiened structure was studied experimantaly in open channel as a device for measuring flow in chanel system. From studing the effects of geometrical parameters and hydraulic features by statistical analysing of experimental data the following conclusions may fixed.

a) The major parameters effecting significantly on discharge are $\frac{h}{d}, \alpha, \frac{L}{d}, \frac{P}{d}$.
b) The value of C_d increases with the increase of h/d and decreases with the decrease of oblique angle but the capacity of the structure increase.
c) The value of C_d decreases with increases (L/d) and (P/d).
d) The value of C_d range from 0.623 to 0.403, with Standard Error 0.0047
e) Within the limitations of the present experimental work a discharge prediction (Equation5) is developed with mean percent error of 0.030 %.
f) A simple discharge prediction (Equation7) with mean percent error of 1.459 %.

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