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Determination of the General Formula to Estimate the Discharge Quantity of Composite Structure for Free Flow

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ABSTRACT

River and open channel flow measurement is regarded as an important element in improving water system management. An experimental analysis in a laboratory flume has been executed to obtain formulas which can be used to predict the discharge quantity which crosses over the sharp crested weir and under the gate in the composite structure which is a tool of flow measurement. These formulas are applied for the free flow condition. Different configurations of composite structure have been used. These configurations have regular and irregular shapes. The derivation of the discharge quantity equation is based on the dimensional analysis which is employed to analyze the factors that control the operation of the composite structure. The family of formulas consists of eight formulas that are divided into two groups. The first group consists of four formulas which are derived based on the variable that dominates the hydraulic behavior of the composite structure, while the second group consists of four formulas based on the same variables of the first group but taking into consideration the effect of weir and gate shape by adopting the hydraulic radius of weir and gate. Based on the evaluation process, all formulas can be used perfectly well to predict the discharge quantity, regardless of the shape of weir and gate. On the other hand, based on the validation process, the formula that considered the effects of shape geometry, flow and fluid properties has given the best prediction of the discharge quantity.

1. INTRODUCTION

Weir- gate hydraulic structure may be simply defined as the irrigation structure which is spread wide and used in hydraulic system water work. This system accomplishes several tasks such as distributing, diverting, monitoring and measuring water for free flow and submerging flow conditions, respectively, under a reasonable operation [1]. Several researchers dealt with this hydraulic structure owing to its important role in water work. The discharge coefficient of combined hydraulic structure is examined. The stated that the hydraulic structure, consisting of a rectangular notch, has various widths and a gate with a semi-circular section that has a constant diameter. In this study, the vertical distance between weir and gate is varied. In this respect, a multi-regression model is employed to calculate the combined discharge coefficient of the hydraulic structure [2]. The combined discharge coefficient for free flow of the combined hydraulic structure is examined. With this regard, the weir of combined structure comprises three portions of the rectangular notch, located over the triangular notch and the trapezoidal notch existed between them while the gate has a semicircular shape. Also, they obtained a formula to predict the combined discharge coefficient of the hydraulic structure. They found that the discharge coefficient of the combined weir-gate structure has range from 0.358 to 0.426 with an average value equal to 0.392 [3]. An experimental study is carried out to appreciate the hydraulic characteristics of notches and combined the hydraulic structure by adopting various shapes of the notch and the combined weir-gate structure. This study illustrated that the combined semicircular notch over the semicircular gate shows a preferable discharge coefficient [4]. The combined discharge coefficient of the hydraulic structure which comprised the combined weir and the semicircular gate is examined. They deduced that the increase in discharge coefficient is associated with the hydraulic variables increasing (H/D, H_1/D, H_2/D, H_3/D). At the constant value of (X), any increase in (W) will lead to the increase in the combined discharge coefficient and when the value of (Y,Z) increases, it will be considered as a factor showing the decrease of the combined discharge coefficient. Based on this study, they also found a semi empirical formula to predicate the discharge coefficient. Where H: total head, H_1, H_2, H_3: water depth over the first, the second and third notch of the combine weir, D: gate diameter, W: width of the second and third notch of the combine weir. B: flume width. Z: height of the second notch of combine weir. Y: vertical distance between weir and gate [5]. The flow of the hydraulic characteristics over the notch with trapezoidal section and under the gate with rectangular section is examined by performing experimental work to evaluate the impact of water depth at upstream, depth of water flow above the sharp crested notch, and the notch angle of trapezoidal section on the combined discharge coefficient of hydraulic structure, respectively. Also, by utilizing the dimensional analysis with the STATISTICA software, they predicted an empirical equation to calculate the combined discharge coefficient. The dimensional analysis was dealt with the following: upstream water depth, water depth above weir, water depth at the gate and trapezoidal weir angle [6]. The fluent software is utilized to appreciate the combined weir-gate hydraulic characteristics. From the results obtained, they deduced that any rise in the combined discharge coefficient will lead to a rise in the discharge quantity. In this work, the combined hydraulic structure comprises the rectangular gate and rectangular weir [7]. An experimental study is performed to examine the combined discharge coefficient of the weir-gate structure. The weir consists of two portions of rectangular notches over the trapezoidal notch with various gate shapes (rectangular gate, semicircular gate and triangular gate). The study concentrated on the influence of geometrical dimension and hydraulic characteristics on the combined discharge coefficient of the hydraulic structure. Out of this study, they obtained three nonlinear formulas to estimate the discharge coefficient, depending on the geometrical and hydraulic variables [8]. The effect of the dimensional parameters and non-dimensional parameters on the hydraulic behavior of the combined hydraulic structure is investigated by employing three various shapes of combine hydraulic structures (triangular gate with triangular notch, rectangular gate with rectangular notch and trapezoidal gate with trapezoidal notch) [9]. The interference between the under flow and the over flow for the combined hydraulic structure comprising of parabolic gate with the parabolic weir is investigated. This study deals with the interaction between the geometrical dimensions and the hydraulic characteristics [10]. Further, the effect of utilized combined hydraulic structure consisting of a gate with non-regular shape (half ellipse) and with various weir shapes (parabolic weir, triangular weir, and rectangular weir), regarding the hydraulic variables and the geometrical variables is investigated. From the results they found that the used of gate with nonregular shape with any shape of weir in the composite hydraulic structure is better. Also, they found that the use of nonregular shape for both weir and gate in the composite structure give a noticeable influence on the hydraulic variables. They found good results in using a non-regular gate with a non-regular weir [11]. The vital role of the major and minor factors which were prevalent on the weir-gate hydraulic structure behavior is explained, like the discharge coefficient [12]. A comparative study depending on the impact of bed flume with or without the contraction on the obtained values of composite hydraulic structure discharge coefficient is made. This study showed the influence of the hydraulic variables on the discharge coefficient, like discharge quantity, flow velocity, Froude number, Reynolds number, and downstream water depth average [13]. The main objective of the current work is based on finding out general discharge formula of the combined weir-gate hydraulic structure which is used to calculate the total discharge regardless of the shape of weir and gate, whether the shape is regular or irregular.

2. EXPERIMENTAL WORK

A set of 86 experimental works were carried out in a flume at the hydraulic laboratory of Basra Engineering Technical College. The flume is 200cm long, has 15cm depth and is 7.5cm wide with a horizontal bed. Eight groups of composite hydraulic structure are used to drive the discharge quantity. The depth of the water is measured by using the point gauge, while the discharge quantity is measured by using the method of volume. Table 1 illustrates the measurements of the model which is manufactured from wood material. Models are made of 5 mm thick wood sheet beveled along all edges at 45 with sharp edges of 1 mm thick. Models are fixed to flume using supports made of plexiglass. The choice of model material and model flume was based on the laboratory facilities available. Here, the experimental works are classified into two parts. The first part includes a selection of 66 runs, randomly chosen for evaluation and the second part includes the other 20 runs for validation.

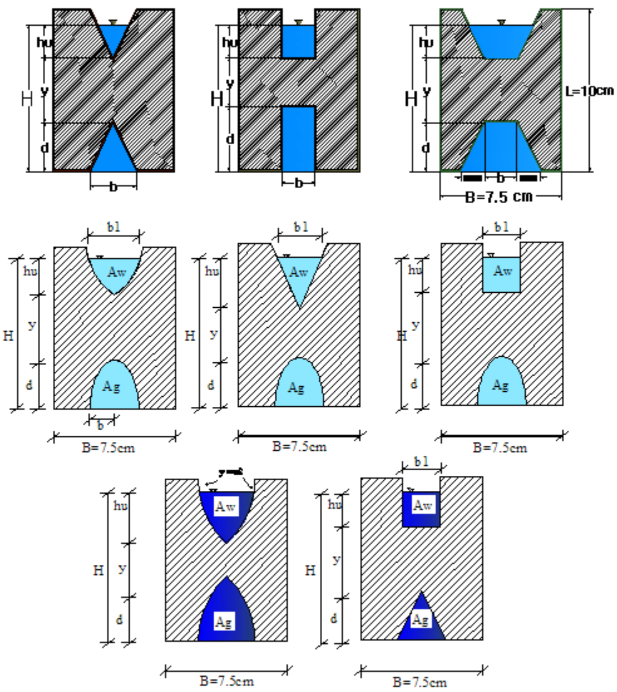


Figure 1. The definition of combined flow over weir and under gate used in the present study

Table 1. The Dimensions and details for different shapes of weir and gate

Shape		h_u	y	d	b	b1	H
Weir	Gate	(cm)	(cm)	(cm)	(cm)	(cm)	(cm)
Parabolic	Parabolic	1 to 3	2 to 6	2 to 4	--	--	7 to 9
V-notch	Triangle	1 to 3	3 to 5	2 to 3	2 to 2.8	1.07 to 2.8	8 to9
Rectangle	Rectangle	1 to 3	2 to 4	2 to 4	2	2	7 to 9
Trapezoidal	Trapezoidal	1 to 3	2 to 5	2 to 4	2	2	8 to 9
Triangle	Ellipse	1 to 3	3 to 4.5	2.5 to 3	2.59	1.5	7 to 9
Rectangle	Ellipse	1 to 3	3 to 4.5	2.5 to 3	2.31	1.5	7 to 9
Parabolic	Ellipse	1 to 3	3 to 4.5	2.5 to 3	3.46	1.25	7 to 9
Rectangle	Triangle	1 to 3	2.34 to 3.34	3.34	2.5 to 5	5.00	7 to 9

The variables that used in Table 1 can defined as follow:

H: water depth at upstream (H= d + y + h_u)
h_u: weir water head
y: vertical distance between weir and gate
d: gate opening depth
b: gate width
b1: weir width

The derivation of general equation is based on the assumption that both weir and gate have the same discharge coefficient under the free flow condition. Figure 1 shows all the details of the adopted weir-gate structure in the present study.

3. DIMENSIONAL ANALYSIS

The weir-gate structure operation is affected by several variables. These variables are adopted in derivative of discharge quantity equation when the hydraulic structure is operated under the free flow condition. The discharge quantity (Q) is written as a function of the geometry variables, flow variables, and fluid variables. The geometry variables are represented by water flow that crosses the gate (A_g), water flow that crosses the weir (A_w), channel width or flume width (B), and the vertical distance between weir and gate (y), while the flow variables are represented by upstream water flow velocity (V_u), water depth at upstream (H) and acceleration due to gravity (g). Also, the fluid variables are represented by water density (ρ) and absolute viscosity (μ). Then, from the dimensional analysis the following function is obtained:

$$Q = f\,(A_g, y, A_w, H, B, V_u, g, \rho, \mu) \tag{1}$$

where, f represents the unknown function and the functional relationship which describes the discharge quantity that is normalized with the distance between weir and gate (y). The flow velocity is written as:

$$\frac{Q}{V_u\, y^2} = f\,(\frac{A_g}{y^2}, \frac{A_w}{y^2}, \frac{H}{y}, \frac{B}{y}, \frac{y\,g}{V_u^{\,2}}, \frac{\mu}{\rho V_u y}) \tag{2}$$

It is observed that Eqns. (1) and (2) do not include the influence of weir and gate shape. The shape effect is added by the adoption of the hydraulic radius for weir and gate, therefore, the water flow that crosses the gate (Ag) and the water flow that crosses the weir (Aw) are replaced by Hydraulic radius of gate (R_g) and Hydraulic radius of weir (R_w), respectively. So, from the dimensional analysis the following function is obtained:

$$Q = f\,(R_g, y, R_w, H, B, V_u, g, \rho, \mu) \tag{3}$$

The functional relationship which describes the discharge quantity is normalized with the distance between weir and gate (y). The flow velocity is written as:

$$\frac{Q}{V_u\, y^2} = f\,(\frac{R_g}{y}, \frac{R_w}{y}, \frac{H}{y}, \frac{B}{y}, \frac{y\,g}{V_u^{\,2}}, \frac{\mu}{\rho V_u y}) \tag{4}$$

4. METHODOLOGY

The relationship between the discharge quantity that crosses the composite structure and the various variables that govern the composite structure's hydraulic behavior is not an easy task. To obtain an effective formula between the discharge quantity and the different variables that are mentioned in dimensional analysis and the curve fitting between the discharge quantity and those variables should be achieved. Linear, nonlinear, exponential and power functions can be described by referring to the relationship between these variables and the discharge quantity. Depending on the mathematical behavior that emerges from the curve that matches between the discharge quantity and any variable, it is seems possible to derive the equation family that describes the rational relationship between the discharge quantities and the dominates variables. Depending on the nature of the resulting relationships between the discharge quantity and the influencing variables individually and entering the considering data (66 sets of data) into the Curve Expert Professional program software, a group of formulas can be obtained to predict the discharge quantity, passing through the composite hydraulic structure. For the purpose of checking the efficiency of the formulas, an evaluation was made for each extracted formula, using the correlation coefficient (r), Nash-Sutcliffe (E), mean square error (MSE), and standardization root means squire error (RSR) see [14-17]. The r value is an indicator of capability of correlation between the measured and the modeled values. When the value of r gets closer to 1 or -1, the regression is now perfect.

The E value indicates how well the plot of measured versus predicted value fits the 1:1 line. As the value of E gets closer to 1 the performance will be perfect. The MSE is the average square deviation of the predicted value from the measured value. The range of MSE lies between zero (perfect fit) and infinity. (RSR) were used to measure the quality of fit employed to assess model estimation. Whenever the value of RSR getting close to zero, this indicates the efficiency of the model is perfect because it is a measure of the extent of errors in the regression results. The value of RSR is calculated from dividing the root mean square error (RMSE) by using standard deviation of the measured data.

Also, the validity of the results was checked by using (20 sets of data) and by finding the (r^2) and (RSR). The value of r^2 lies in between 0 and 1. This value details shows how the value of the measured dispersion correlates to the previous prediction. If the value is zero, then that means it was not at all related, and if the value is 1, then that means it was 100% equal in dispersion. However, r^2 is regarded an imperfect system if it is the only value taken into account, regardless of the value of the prediction, we can get r^2 values that are close to 1 even if the predictions were far off from the measured value. Thus, predictions for the measured dispersion must be taken into account, in addition to r^2, gradient (a1) and intercept (a) that are used. In this system, the intercept should be close to zero and the gradient should be close to one.

5. RESULTS AND DISCUSSION

For results gained from the experimental study, the 66 runs are employed to predict the family formulas which are used to estimate the discharge quantity of composite structure and 20 runs are employed to verify from the suitability of the derived formulas.

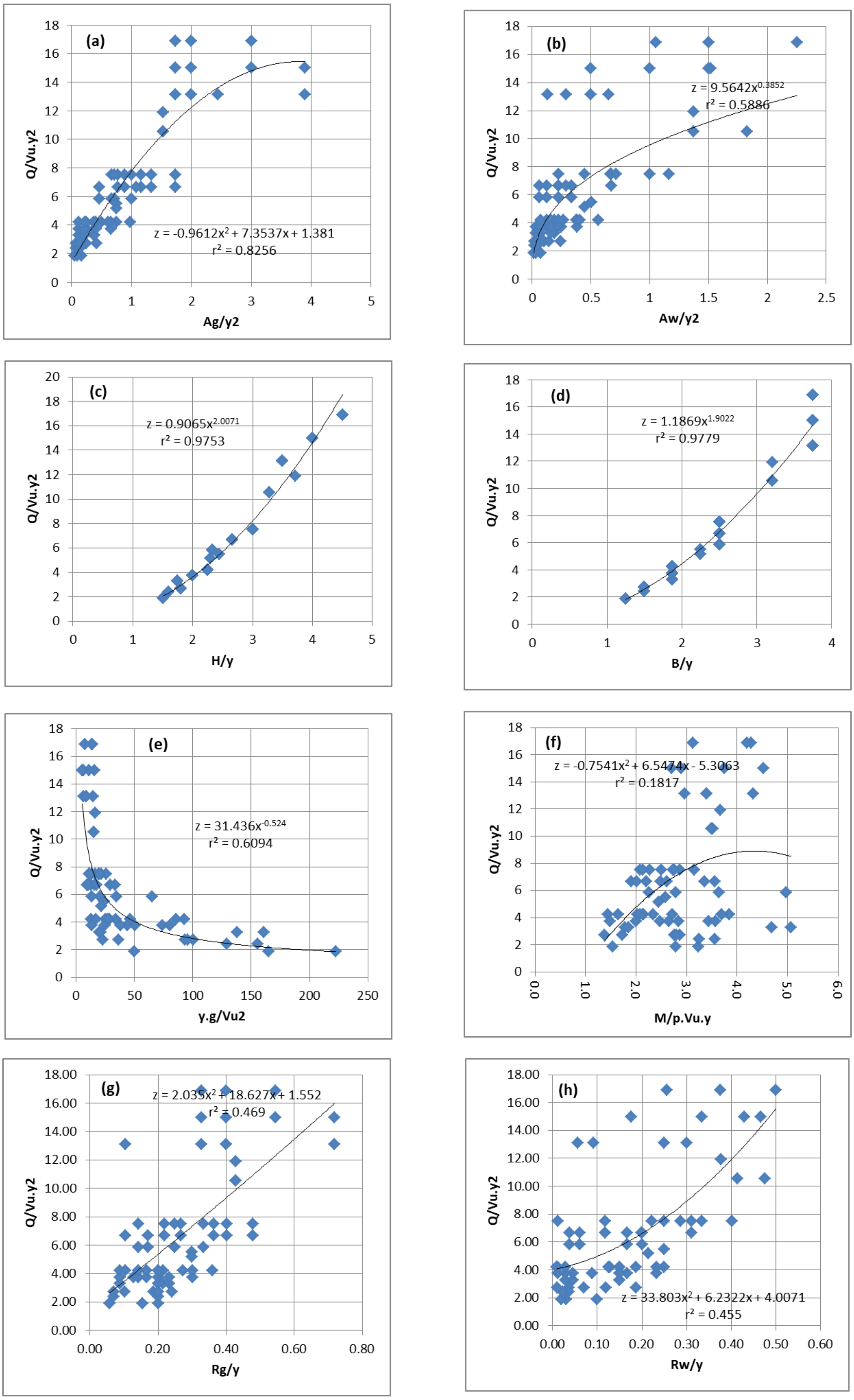


Figure 2. The relationship between the dimensionless value of discharge quantity $Q/V_u y^2$ and the dimensionless values of state variables

5.1 Behavior of the variables with quantity of discharge

Figures 2a to 2f illustrate the relationship between the dimensionless value of quantity of discharge, represented by the ratio $Q/V_u y^2$ and the dimensionless values of all variables, represented by the area of gate ratio A_g/y^2, area of weir ratio

A_w/y^2, upstream water head ratio H/y, width of water surface at upstream region ratio B/y, distance between weir and gate ratio yg/V_u^2, and properties of fluid ratio $\mu/\rho V_u y$. It is obvious from these figures that the ratio $Q/V_u y^2$ has positive proportional relationship with all variables except with the ratio yg/V_u^2. Here, y is considered constant and the upstream water flow velocity (V) has minor effect on the relationship. So, any increase in cross sectional area of flow that crosses the gate and/or weir leads to an increase in the discharge of the gate and/or weir, and this will be reflected on the discharge quantity of the composite structure. Also, any increase in upstream water head ratio H/y or width of water surface at upstream region ratio B/y leads to an increase in the quantity of discharge of composite structure. This is due to the fact that any increase in upstream water head or width of water surface at upstream region will be reflected on the cross sectional areas of flow which crosses the gate and weir. So, this will lead to an increase in the quantity of discharge of composite structure. Furthermore, it is observed that when the ratio $\mu/\rho V_u y$ increased the ratio, $Q/V_u y^2$ will also be increased but with small increment, therefore, the influence of the increase can be considered less significant as compared with other ratios. On the other hand, it is obvious that when the ratio yg/V_u^2 increased, the ratio $Q/V_u y^2$ will decreased. Here, the upstream water flow velocity (V_u) has a minor effect on this relationship and when the vertical distance between the weir and the gate (y) increases it leads to the decrease in quantity of discharge of composite structure owing to the large quantity of water that will be confined behind the distance (y). Figures 2g and 2h illustrate the relationship between the quantity of discharge ratio $Q/V_u y^2$ and the shape of gate ratio R_g/y and shape of weir ratio R_w/y. It is obvious from figures that when the ratio R_g/y and ratio R_w/y increased the ratio $Q/V_u y^2$ will be increased. As it has been mentioned above that y is considered constant and the upstream water flow velocity (V_u) has minor effect on the relationship, so, any increase in cross sectional area of flow that crosses the gate and/or weir as well as the wetted perimeter of gate and/or weir, will lead to increase in hydraulic radius of the gate and weir and this will be reflected on quantity of discharge of composite structure. The type of relationship between dimensionless values of quantity of discharge represented by the ratio $Q/V_u y^2$ and the dimensionless values of all state variables are determined. It is observed that the variables A_g/y^2, $\mu/\rho V_u y$, and R_g/y display nonlinear function relationship as is shown in Figures 2a, 2f and 2g, while the variables A_w/y^2, H/y, B/y, yg/V_u^2, and R_w/y display power function relationship as is shown in Figures 2b, 2c, 2d, 2e and 2h. Also, the variables A_g/y^2, H/y, and B/y give very good and perfect correlation with $Q/V_u y^2$ respectively. The variables A_w/y^2, yg/V_u^2 , R_g/y, and R_w/y give fair relationship with $Q/V_u y^2$, while the variable $\mu/\rho V_u y$ gives very poor relationship.

5.2 Formulas based on first option

Nonlinear regression analysis of 66 experimental runs is performed by the adoption of the professional expert software to derive family of formulas. This family consists of four equations which are derived from the first option represented by Eq. (2) of dimensional analysis. The first formula represents the general equation which includes all proposed dimensionless variables of the first option.

$$\frac{Q}{V_u\,y^2} = -5.0 + 0.0073\left(\frac{A_g}{y^2}\right)^2 + \left(\frac{A_w}{y^2}\right)^{-0.064} + \left(\frac{H}{y}\right)^{1.59} + \left(\frac{B}{y}\right)^{1.62} + \left(\frac{y\,g}{V_u^{\,2}}\right)^{0.18} - 0.035\left(\frac{\mu}{\rho V_u y}\right)^2 \quad (5a)$$

Based on the behavior of the variables with the quantity of discharge that has been discussed above, formula (5a) includes some limits which have significant and strong effect on the quantity of discharge. Also this formula includes some limits which have minor effect. So to refine this formula, the limit $\mu/\rho V_u y$ is eliminated to obtain the following formula:

$$\frac{Q}{V_u\,y^2} = -4.63 + 0.035\left(\frac{A_g}{y^2}\right)^2 + \left(\frac{A_w}{y^2}\right)^{-0.08} + \left(\frac{H}{y}\right)^{1.6} + \left(\frac{B}{y}\right)^{1.54} + \left(\frac{y\,g}{V_u^{\,2}}\right)^{0.1} \quad (5b)$$

Another refinement could be made by eliminating the limit A_w/y^2 in addition to the elimination of the limit $\mu/\rho V_u y$ from the formula (5a) to obtain the following formula:

$$\frac{Q}{V_u\,y^2} = -3.63 + 0.035\left(\frac{A_g}{y^2}\right)^2 + \left(\frac{H}{y}\right)^{1.58} + \left(\frac{B}{y}\right)^{1.56} + \left(\frac{y\,g}{V_u^{\,2}}\right)^{0.12} \quad (5c)$$

A final modification can be obtained by eliminating the limits $\mu/\rho V_u y$, A_w/y^2 and yg/V^2 from formula (5a) to obtain the formula below. The elimination of the limits depends on the effectiveness of these limits on the quantity of discharge of composite structure.

$$\frac{Q}{V_u\,y^2} = -1.92 + 0.026\left(\frac{A_g}{y^2}\right)^2 + \left(\frac{H}{y}\right)^{1.57} + \left(\frac{B}{y}\right)^{1.54} \quad (5d)$$

5.3 Formulas based on second option

Nonlinear regression analysis of 66 experimental runs is performed by using professional expert software to derive family formulas. This family consists of four formulas which are derived based on second option (represented by Eq. (4)) of dimensional analysis. The first formula represents the general equation of second option which includes all proposed dimensionless variables of second option.

$$\frac{Q}{V_u\,y^2} = -4.0 + 0.071\left(\frac{R_g}{y}\right)^2 - 0.25\left(\frac{R_w}{y}\right)^2 + \left(\frac{H}{y}\right)^{1.58} + \left(\frac{B}{y}\right)^{1.65} + \left(\frac{y\,g}{V_u^{\,2}}\right)^{0.2} - 0.039\left(\frac{\mu}{\rho V_u y}\right)^2 \quad (5e)$$

Based on the behavior of variables with quantity of discharge that was discussed above, formula (5e) includes some limits which have significant and strong effect on the quantity of discharge. Also, this formula includes some limits which have minor effect. So, to refine this formula the limit $\mu/\rho V_u y$ is eliminated to obtain the following formula:

$$\frac{Q}{V_u\,y^2} = -3.72 + 0.065\left(\frac{R_g}{y}\right)^2 - 0.2\left(\frac{R_w}{y}\right)^2 + \left(\frac{H}{y}\right)^{1.58} + \left(\frac{B}{y}\right)^{1.59} + \left(\frac{y\,g}{V_u^{\,2}}\right)^{0.14} \quad (5f)$$

Another refinement could be made by eliminating the limit R_w/y from formula (5f) to obtain the following formula:

$$\frac{Q}{V_u\,y^2} = -3.72 + 0.58\left(\frac{R_g}{y}\right)^2 + \left(\frac{H}{y}\right)^{1.58} + \left(\frac{B}{y}\right)^{1.59} + \left(\frac{y\,g}{V_u^{\,2}}\right)^{0.14} \qquad (5g)$$

A final modification can be obtained by eliminating the limit yg/V^2 from formula (5g) to obtain the following formula:

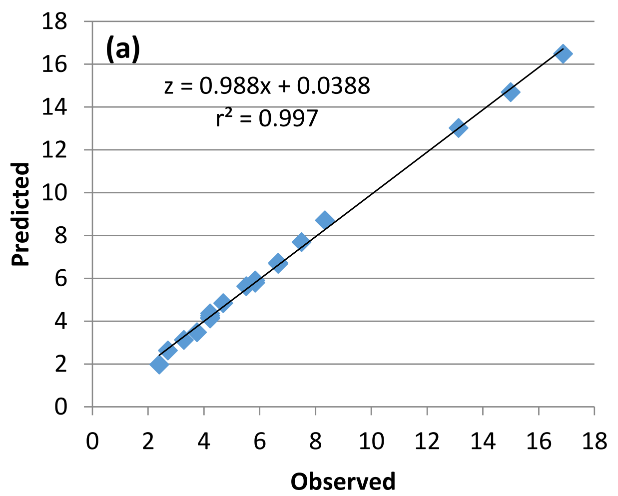
$$\frac{Q}{V_u\,y^2} = -1.95 + 0.116\left(\frac{R_g}{y}\right)^2 + \left(\frac{H}{y}\right)^{1.57} + \left(\frac{B}{y}\right)^{1.57} \qquad (5h)$$

The elimination of limits depends on the effectiveness of these limits on the quantity of discharge of composite structure.

The output details of statistical analysis for the suggested equations are illustrated in Table 2. These details were included in the following; correlation coefficient, Nash-Sutcliffe, mean square error, root mean square error and standardization root means squire error. It is clear from Table 2 that the values of the correlation coefficient and Nash-Sutcliffe are nearest to the unity. Also, there is no limited value for MSE or RMSE. The lower the value the better and 0 means the model is perfect. Since there is no limited value, the MSE and RMSE basic value are in selecting one prediction model over another. It is observed from Table 2 that the value of MSE, RMSE as well as RSR are closer to zero. This implies a reasonable result for all the derived equations.

Table 2. Statistical characteristics and comparison between the predicted equations

Equation No.	r	E	MSE	RMSE	RSR
5a	**0.9993**	0.9936	0.0326	0.1805	0.0424
5b	0.9988	0.9968	0.0561	0.2369	0.0557
5c	0.9989	0.9969	0.0548	0.2340	0.0550
5d	0.9984	0.9969	0.0547	0.2339	0.0549
5e	0.9983	0.9906	0.1660	0.4075	0.0958
5f	0.9988	0.9975	0.0435	0.2087	0.0490
5g	0.9988	**0.9978**	**0.0377**	0.01942	0.0456
5h	0.9988	0.9966	0.0593	0.2435	0.0572



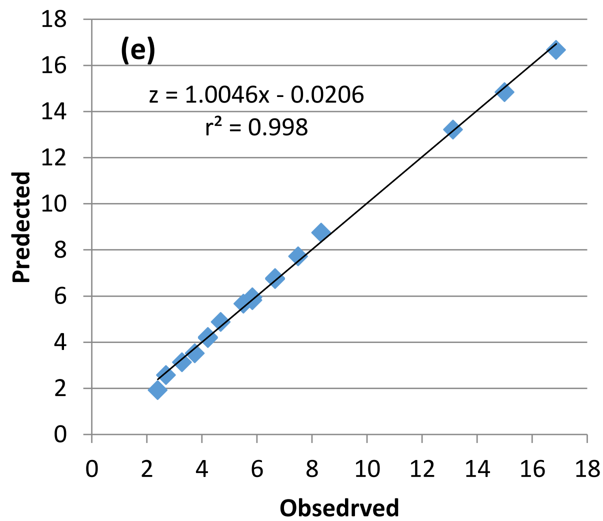


Figure 3. The coefficient of determination and the values of (a) and (a1) coefficients for the a: derived formula (a) and e: derived formula (e)

Table 3. Data of validation (g=981cm/sec^2, B=7.5 cm, μ/ ρ =10^{-2} cm^2/sec)

Q_{act} cm^3/sec	V_u cm/sec	y cm	A_g cm^2	A_w cm^2	H cm	R_w cm	R_g cm
728.16	10.79	4.0	6.93	0.54	9.00	0.183	0.655
750.00	11.11	4.0	4.20	2.00	9.00	0.354	0.512
779.22	11.54	3.0	4.20	4.20	9.00	0.512	0.512
410.02	7.81	4.0	4.00	2.00	7.00	0.500	0.667
801.42	13.36	4.0	6.00	6.00	8.00	0.857	0.857
738.92	12.32	3.0	6.00	4.00	8.00	0.667	0.750
774.53	12.91	3.0	9.00	6.00	8.00	0.857	1.000
952.38	18.14	2.0	12.0	3.00	7.00	0.600	1.091
762.71	12.71	5.0	6.07	2.59	8.00	0.599	0.933
768.57	11.39	4.0	6.07	10.47	9.00	1.203	0.933
802.14	15.28	3.0	10.47	2.59	7.00	0.599	1.203
1045.30	15.49	2.0	15.60	10.47	9.00	1.203	1.437
786.71	13.11	2.0	9.76	3.63	8.00	0.050	0.208
591.72	8.77	5.0	6.44	1.15	9.00	0.114	0.714
620.26	10.34	3.0	6.44	3.63	8.00	0.050	0.429
728.74	11.19	3.3	8.33	5.00	8.68	0.769	0.998
534.12	7.913	3.5	4.909	3.897	9.00	0.596	0.791
801.42	11.873	4.0	7.069	4.620	9.00	0.732	0.973
790.17	10.536	4.0	7.069	6.928	10.0	0.989	0.973
799.29	10.657	3.0	7.069	6.928	10.0	0.794	0.973

Table 4. Validation of formula (5e)

R_g/y^2 (1)	R_w/y^2 (2)	H/y (3)	B/y (4)	$y.g/V_u^2$ (5)	$\frac{\mu}{\rho V y}$ (6)	$Q/V_u. Y^2$ (7)	$Q/V_u. Y^2$ (8)
0.163	0.045	2.2	1.87	33.68	2.31	4.218	4.235
0.127	0.088	2.2	1.87	31.75	2.25	4.21	4.22
0.170	0.170	3	2.5	22.06	2.88	7.50	7.73
0.166	0.12	1.75	1.87	64.26	3.20	3.28	3.14
0.214	0.214	2	1.87	21.97	1.71	3.75	3.52
0.250	0.222	2.67	2.50	19.38	2.70	6.66	6.76
0.333	0.285	2.67	2.50	17.64	2.58	6.66	6.74
0.545	0.300	3.5	3.75	5.95	2.75	13.12	13.22
0.186	0.119	1.6	1.50	30.33	1.57	2.40	1.93
0.233	0.300	2.25	1.87	30.23	2.19	4.21	4.19
0.401	0.199	2.34	2.50	12.59	2.18	5.83	5.82
0.718	0.617	4.50	3.75	8.17	3.22	16.87	16.68
0.104	0.025	4.00	3.75	11.40	3.81	15.00	14.85
0.142	0.022	1.80	1.50	63.76	2.28	2.70	2.57
0.142	0.016	2.67	2.50	27.51	3.22	6.66	6.78
0.298	0.230	2.59	2.24	26.12	2.67	5.83	5.95
0.225	0.170	2.57	2.14	54.77	3.61	5.51	5.67
0.243	0.183	2.25	1.87	27.80	2.10	4.21	4.19
0.243	0.247	2.50	1.87	35.31	2.37	4.68	4.88
0.324	0.264	3.34	2.50	25.88	3.12	8.33	8.76

Table 5. Validation results of all formulas

Equation No.	r^2	a	a1	RMSE	RSR
9a	0.997	0.0388	0.998	0.2009	0.0503
9b	0.997	**-0.0006**	0.998	0.1955	0.0489
9c	0.997	-0.0208	1.004	0.2050	0.0513
9d	0.997	0.08	0.996	0.2184	0.0546
9e	**0.998**	-0.020	1.004	**0.1907**	**0.0476**
9f	0.996	0.066	0.985	0.2448	0.0612
9g	0.996	0.035	**0.999**	0.2302	0.0576
9h	0.996	0.125	0.993	0.2475	0.0619

5.4 Validation

Table 3 contains the data of 20 experimental works which is used to feed the formula 5a to 5h in order to estimate the quantity of discharge of composite structure. While Table 4 contain the information of formula 5e in addition to the quantity of discharge which is calculated from formula 5e, quantity of discharge which is calculated from experimental work. For Table 4, column (7) represents the result of experimental work while column (8) represents the result which is obtained from formula 5e. So the formula can be used without any confusion or conflict. Table 5 show the values of the coefficient of determination and the values of (a), (a1), RMSE, RSR parameters for the derived equations. Also, Figures 3a and 3e show the values of the coefficient of determination, value of (a), and (a1) for arbitrary case. It is clear from Table 5 that the values of (a) are nearest to zero and the values of (a1) are nearest to the unity. The values of (a) and (a1) imply that the derived equation can give a suitable prediction for estimating the quantity of discharge. It is observed that the value of coefficient (a) of formula (9e) is closer to zero and the value of coefficient (a1) of the same formula is almost equal to one. On the other hand, it is observed that the minimum values of RMSE and RSR are achieved in formula (9e), therefore, it is expected that the formula (9e) will give the best prediction to the quantity of discharge.

6. CONCLUSION

The flow below gate and over weir in composite structure was investigated experimentally in flume or open channel as a measurement device. So, the main points to conclude from this work are:

1- Reasonable formulas are derived and based on the mathematical trends among the quantity of discharge and the variables which control the hydraulic behavior of composite structure.
2- The hydraulic radius can be used to express the influence of weir and gate shape.
3- The water's physical properties have minor effect on the quantity of discharge of composite structure.
4- The statistical analysis can be considered as an important subject in the description of the suitability of family formulas.
5- The upstream velocity has minor effects on the quantity of discharge of composite structure.
6- The vertical distance between the weir and the gate has a significant role in estimating the quantity of discharge.
7- The fluid variables have less effect on estimating the discharge quantity and the best formula is the one that considered the shape geometry, flow and fluid variables.

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NOMENCLATURE

B	Flum Width, L
H	Water depth at upstream, L
g	Gravitational acceleration, $L.T^{-2}$
y	Vertical distance between weir and gate, L
d	Gate opening depth, L
b	Gate width, L
b1	Weir width, L
hu	Weir water head, L
A	Area, L^2
V	Velocity, L/T
R	Hydraulic radius, L
Q	Discharge, L^3/T
r	Correlation coefficient
r^2	Coefficient of determination
MSE	Mean square error
RMSE	Root mean square error
RSR	Standardization root means squire error
E	Nash- Sutcliffe coefficient

Greek symbols

ρ	Fluid density, M/L^3
μ	dynamic viscosity, $M. L^{-1}.T^{-1}$

Subscripts

g	gate
w	weir
u	upstream
d	downstream