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INVESTIGATING FLOW CHARACTERISTICS UNDER EFFECT OF A MODIFIED VERTICAL GATE*

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ABSTRACT:

There is no doubt that, the gates one of the most important controllers of the flow through regulators. Several studies had been conducted to improve the gates' performance by modifying its features to improve the flow characteristics. It can be said that, no studies focused on the gate as an energy dissipater. The present paper investigates the possibility of using the gate as a tool of the flow controlling through the basin itself. We have provided a new idea based on perforating of a hole in the gate itself. It plays an important rule to improve the hydraulic jump's characteristics and the coefficient of discharge. Theoretical models are built to simulate each of the dissipated energy values and Froude's number. The laboratory experiments achieved promising results. It was found that, the case of sluice gate with a circular opening and plastic hose of inclination angle = 330o reduces the relative jump depth and the relative jump length by 12.3% and 29%, respectively. In addition, it increases the average values of the dissipated energy and the coefficient of discharge by 8% and 16.5%, respectively. Statistical analysis is used in the construction of equations to simulate the above-mentioned parameters.
KEY WORDS: Gate opening, Coefficient of discharge, Hydraulic jump, Flow characteristics, and Intelligent gate.

ENQUÊTE CARACTÉRISTIQUES D'ÉCOULEMENT SOUS L'EFFET D'UNE VERTICALE GATE MODIFIÉ

RÉSUMÉ:

Il ne fait aucun doute que, les portes sont l'un des contrôleurs les plus importantes de l'écoulement à travers les organismes de réglementation. Plusieurs études ont été menées pour améliorer la performance des portes en modifiant leurs fonctionnalités pour améliorer les caractéristiques d'écoulement. On peut dire que, pas d'études axées sur la porte comme dissipateur d'énergie. La présente étude examine la possibilité d'utiliser la grille comme moyen de contrôler l'écoulement à travers le bassin lui-même. Nous avons fourni une nouvelle idée sur la base perforée d'un trou dans la porte elle-même. Il joue un rôle important pour améliorer les jumpcharacteristics hydrauliques et le coefficient de décharge. Les modèles théoriques sont conçus pour simuler chacune des valeurs d'énergie dissipée et la profondeur relative du saut en aval de la grille. Les expériences en laboratoire ont obtenu des résultats prometteurs. Il a été constaté que, le cas de la porte d'écluse avec une ouverture circulaire et tuyau d' angle d'inclinaison = 150 ° réduit la profondeur de saut relatif et la longueur de saut relatif de 12,3 % et 29 % , respectivement . En outre, elle augmente les valeurs moyennes de l'énergie dissipée et le coefficient de débit de 8% et 16,5 % , respectivement . L'analyse statistique est utilisée dans la construction d'équations pour simuler les paramètres mentionnés ci-dessus.
MOTS CLÉS: Ouverture Porte, Coefficient De Décharge, Saut Hydraulique, Les Caractéristiques De Débit Et Porte Intelligente

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1. INTRODUCTION

Hydraulic jumps have been used for dissipating the excess energy in the downstream apron of water structures through generation of a flow turbulence. The free jump, which happens in wide rectangular flat channels with leveled bed, is defined as a classical jump and has been widely studied (**McCorquodale [16]**, **Hager [8], Unami et al [21]** and **Mohsen et al [14]**). **Sanjeev et al [11],** investigated and discussed the hydraulic jump in flat prismatic canal in view of the consequence of both approach Froude number and arriving Reynolds number. **Huber, [9]** investigated the turbulent hydraulic jumps. **Stefano [12]** examined the hydraulic jump that happens in homogeneous and nonhomogeneous coarse bed channels.

On the other hand, many studies had investigated the jump characteristics in non-prismatic channels **(Abdel-Aal et al.[1], Arabhabhirama and Abella [5], Abdelazim, and Yasser [3],Elfiky [6]**, **Negm et al [17] Wanoschek, and Hager [22], Rashwan [19]** and **Javan et al [10]).**

Other researcher tried to make some modification in the basin itself to improve the jump characteristics. **Negm et al [18]** investigated the flow characteristics over weirs and below gates of equal contraction and discussed the results. **Wilson [23]** tested method for the control of jump location by jets to avoid the cavitation's' problems with the blocks and baffles under high heads.

Other approaches tried to modify the water structure itself to improve the flow characteristics. **Abozeid et al. [4]** studied the flow characteristics over weir with bottom hole. **Swamee [13]** concerned with the use of sluice gate.

Flow over existing Fayoum weirs with orifices was calibrated experimentally by **Abdel Halim et al [2]**. **Abdelazim [3]** examined the results of different forms of stilling basin of regulator on the submerged jump length downstream regulator apron. **Mohamed [15]** examined a wide experimental program on a model simulating as suite regulator in hydraulic research institute.

Finally, few papers focused on the perforated vertical gates, Habib [7] studied the characteristics of Flow through Weirs Controlled by a gate with an opening.

The present experimental research aims to study the flow characteristics of through a vertical gate with an opening. It investigates the effect of followings: the relative diameter and height of the opening, the pipe length fitted to the opening, and the sloping of the pipe on the jump characteristics formed downstream the gate.

2. THEORETICAL APPROACH

2.1 Dimensional Analysis

The flow field downstream of the sluice gate depends on many of flow parameters as shown in figure (1). A dimensional analysis is applied to correlate the different variables affecting phenomena under study and the following functional relationships are obtained:

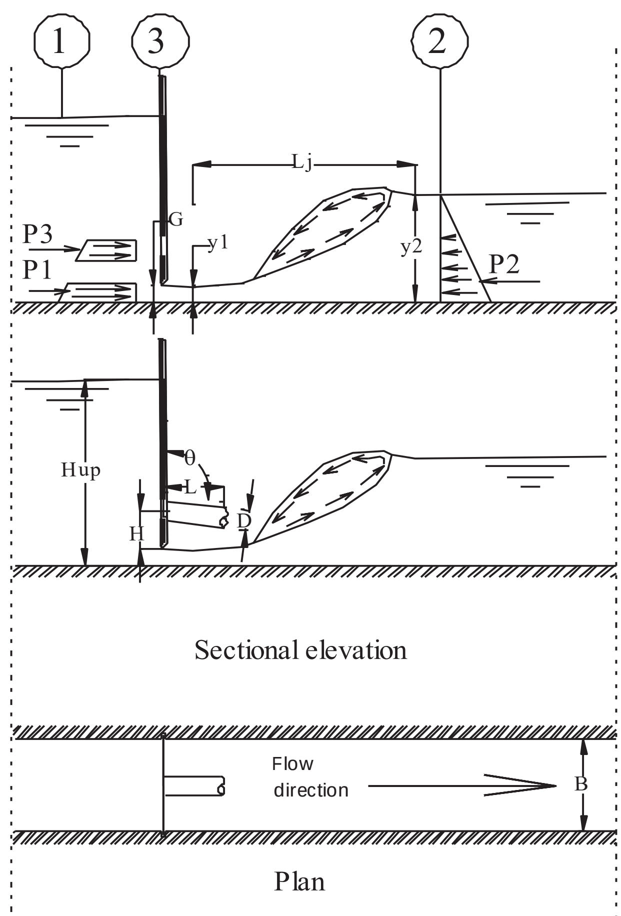


Fig. (1): Definition sketch

$$\frac{y_2}{y_1} = f\left(\frac{H}{y_1}, \frac{D}{y_1}, \frac{L}{y_1}, \sin\theta, \frac{H_{up}}{y_1}, F_1\right) \quad (1)$$

$$\frac{L_j}{y_1} = f\left(\frac{H}{y_1}, \frac{D}{y_1}, \frac{L}{y_1}, \sin\theta, \frac{H_{up}}{y_1}, F_1\right) \quad (2)$$

$$\frac{\Delta E}{E_1} = f\left(\frac{H}{y_1}, \frac{D}{y_1}, \frac{L}{y_1}, \sin\theta, \frac{H_{up}}{y_1}, F_1\right) \quad (3)$$

$$C_d = f\left(\frac{H}{y_1}, \frac{D}{y_1}, \frac{L}{y_1}, \sin\theta, \frac{H_{up}}{y_1}, F_1\right) \quad (4)$$

In which y_2/y_1 is the relative jump depth, L_j/y_1 is the relative jump length, $\Delta E/E_1$ is the relative energy loss through the free jump; H/y_1 is the relative height of the circular opening above the lower edge of the sluice gate; D/y_1 is the relative diameter of the circular opening; L/y_1 is the relative length of the hose fitted in the circular opening; H_{up}/y_1 is the relative water depth upstream the gate; F_1 the initial Froude number; $F_1 = V_1/(gy_1)^{0.5}$; C_d is the coefficient of discharge; and □□ is the angle of inclination of the plastic hose with the vertical axe.

2.2 Relative Depths

The momentum and continuity equations are used to develop a theoretical model for computing the relative depth ratio. The approach involves some assumptions to simplify the studied criteria including the followings: the steady flow, the incompressible liquid, the hydrostatic pressure distribution, the uniform velocity distribution. The turbulence effect and the air entrainment are neglected. By applying the pressure-momentum relationship between sections (3 and 2) one gets.

$$\Sigma F = \rho Q\,(\beta_1 \mathrm{V}_{\mathrm{av}} - \beta_2 \mathrm{V}_2) \quad (5)$$

$$\mathrm{P}_2 - \mathrm{P}_1 - \mathrm{P}_3 = \frac{\gamma}{g}(Q\beta_1 \mathrm{V}_{\mathrm{av}} - Q\beta_2 \mathrm{V}_2) \quad (6)$$

Where:

$$\mathrm{P}_2 = 0.5 \times \gamma B y_2^2 \quad (7)$$

$$\mathrm{P}_1 = 0.5 \times \gamma B G^2 \quad (8)$$

$$\mathrm{P}_3 = \gamma(H_{up} - G - H)(0.25\pi D^2) \quad (9)$$

In which: P_1 is the hydrostatic pressure just upstream of the gate; P_2 is the hydrostatic pressure just downstream

of the jump; P_3 is the hydrostatic pressures on the open gate itself; G is the gate opening; y_2:sequent depth of the jump; H_{up} is the water depth upstream the gate; H is the height of the circular opening above the lower edge of the sluice gate; D is the diameter of the circular opening; V_{av} is the average velocity passing through the opening and the gate the gate; and B is the channel width. Substituting in equation (6) yields.

$$0.5 \times \gamma B\, y_2^2 - \gamma(H_{up} - G - H)(0.25\pi D^2) - 0.5 \times \gamma B G^2 = \frac{\gamma Q}{g}(\beta_1 \mathrm{V}_1 - \beta_2 \mathrm{V}_2) \quad (10)$$

Assuming that β_1 = β_2= 1.0 and applying the continuity equation between section (3) and section (2):

$$0.5 \times \gamma B\, y_2^2 - 0.5 \times \gamma B G^2 - \gamma(H_{up} - G - H)(0.25\pi D^2) = (\gamma \times \mathrm{V}_2 y_2 B/g)(\mathrm{V}_2 A_2/A_1 - \mathrm{V}_2) \quad (11)$$

Dividing Eq. (11) by $0.5 \times \gamma \times \mathrm{B} \times y_2^2$, Let $H_{up}/y_2 = y_r$, $G/y_2 = G_r$, $H/y_2 = H_r$, and $D/y_2 = D_r$, $D/B = D_{Br}$.

$$1 - G_r^2 - \left(\frac{H_{up} - G - H}{y_2}\right)\left(\frac{0.5\pi D^2}{B y_2}\right) = (2\mathrm{V}_2/y_2 g)(\mathrm{V}_2 A_2/A_1 - \mathrm{V}_2) \quad (12)$$

$$\mathrm{F}_2 = \sqrt{\frac{1 - (y_r - G_r - H_r)(0.5\pi D_{Br} D_r) - G_r^2}{2(\mathrm{A_r} - 1)}} \quad (13)$$

2.3 Energy Approach

By applying the energy equation between sections (1 and 2), and assuming the energy coefficients = 1.0, the energy loss can be formulated as follows:

$$\frac{\Delta E}{E_2} = \frac{E_{up}}{E_2} - 1 = \frac{h_{up} + V_{up}^{\,2}/2g}{y_2 + V_2^{\,2}/2g} - 1 \qquad (14)$$

$$\frac{\Delta E}{E_2} = \left[\frac{h_{up}/y_2 + V_{up}^{\,2}/2y_2 g}{1 + V_2^{\,2}/2y_2 g}\right] - 1 \qquad (15)$$

$$\frac{\Delta E}{E_2} = \frac{y_r + (By_2)^2 V_2^{\,2}/(Bh_{up})^2 \times 2y_2 g}{1 + (F_2^2/2)} - 1 \qquad (16)$$

$$\frac{\Delta E}{E_2} = \left[2y_r^{\,3} + F_2^2/(2+F_2^2)\, y_r^{\,2}\right] - 1 \qquad (17)$$

Where E_{up} is the specific energy upstream the gate, and E_2 is the specific energy downstream the jump.

3. VERIFICATION OF DEVELOPED EQUATIONS

Experimental data is used to evaluate the developed equations, (Eqs. 13 and 17). Figures 2 and 3 show the relationship between the theoretical results and the measured experimental data. It can be said that the developed equations prove an acceptable agreement as compared to the observations, (R^2 = 88.9%, and 99.9%, respectively). The values of theoretical F_2 in figure 2 are less than the experimental ones. This may be due to; the theoretical values depend on P_3, which has been considered as a horizontal magnitude only. The assumption canceled the vertical component of the force. Because of the measuring difficulty of the vertical component of P_3. As a result the theoretical values of F_2 are slightly decreased.

4. EXPERIMENTAL SETUP

The experimental work was carried out in the hydraulic lab in the faculty engineering, Zagazig university. It was accompanied in a flume of 3m long×10cm wide×30cm deep. The discharges were measured using pre-calibrated orifice meter fixed in the main flow line. The tailgate was fixed at the end of the experimental part of the flume; it was used to control the tail-water depth. The water depths were measured by means of point gauges. The experimental model was fixed in the first meter of the flume, see Fig. (1). The experimental program is summarized as in table (1), it is including five stages. *Stage I* can be described as the base case. It includes the standard sluice gate without any modifications. It included about 24 experimental runs. Nine-gate opening are used with (i.e., 1.3; 1.5; 1.8; 2.1; 2.3; 2.6; 2.8; 3.0; and 3.5cm). *Stage II* explores the effect of the vertical location of the circular opening perforated in the vertical centerline of the standard sluice gate, (i.e., H =1.0; 2.5; 4.0; and 5.1cm). The opening is of about 0.8cm.

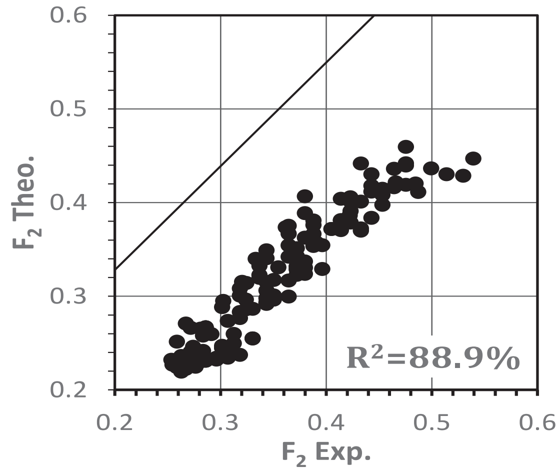


Fig. (2): Relationship between developed equations and experimental measurements for F_2 model Eq. (13)

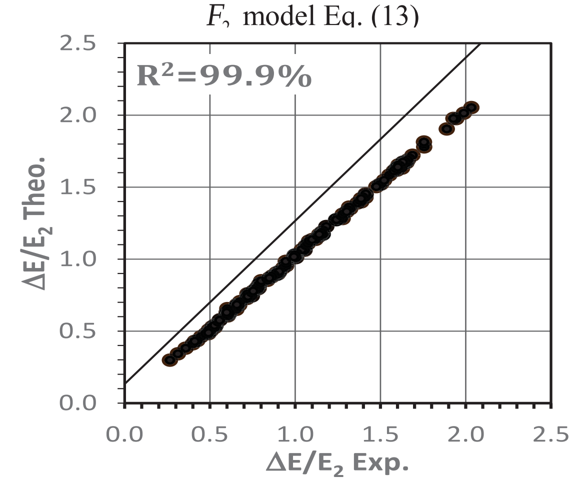
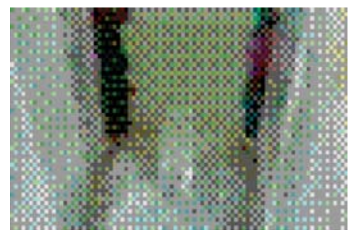


Fig. (3): Relationship between developed equations and experimental measurements $\Delta E/E_2$ model Eq. (17)

Table (1): Scheme of experimental work stages

Stage	Description	Characteristics				Selected photos
		H (cm)	D (cm)	L (cm)	θ (degree)	
I.	The case of the gate without opening	0	0	0	90	
II.	The effect of the vertical location of the opening	1.0 2.5 4.0 5.1	0.8	0	90	
III.	The effect of the diameter of the circular opening	2.5	1.0 1.8 2.1 2.5	0	90	
IV.	The effect of the hose length	2.5	2.5	0 1.5 3.5 4.5	90	
V.	The effect of the hose angle	2.5	2.5	3.5	0 60 300 330	

Stage III explores the effect of the diameter of the opening, (D). It was perforated above the lower edge by 2.5cm. The stage includes four different diameters (i.e., 1.0; 1.8; 2.1; and 2.5cm). *Stage IV* explores the effect of the length of rigid plastic hose fixed at the end of the opening, (L). The hose length includes four different lengths (i.e., L =0.0; 1.5; 3.5; and 4.5cm). *The last stage* explores the effect of the angle of inclination of the plastic hose with the vertical axe, (θ).

A typical test procedure consisted of a gate opening was fixed and a selected discharge was allowed to pass then the tailgate was adjusted until a free hydraulic jump is formed downstream the gate. The flow rate; the water surface profile; the length of jump, L_j, was measured in each case. The Froude number ranges between 1.88 and 9.53.

5. DISCUSSION OF EXPERIMENTAL RESULTS

5.1 Location Effect of the opening

The relations between the initial Froude number; F_1 and each of the relative jump depth y_2/y_1; the relative jump length L_j/y_1 and the relative energy loss $\Delta E/E_1$ for different relative vertical location of the circular opening; (H/y_1 = 0.798, 2.39, 3.174 and 3.834) in case of (D/y_1 = 0.6, L/y_1 = 0.0 and θ = 0°) are shown in figures (4a, 4b, and 4c). The figure shows also the same relation for the case of the standard sluice gate without any modifications.

It clears that that the values of the relative jump characteristics including $y2/y_1$, L_j/y_1 and $\Delta E/E_1$ increase with the increase of the initial F_1. The relative vertical location of the circular opening; H/y_1 = 0.798 gives the minimum values of y_2/y_1 in comparison with the base case. It reduces the average values of y_2/y_1 by about 9%.

The case of H/y_1 = 0.798 increases the lost energy through the jump reach in comparison with the base case by about 7%. Moreover, it reduces the values of L_j/y_1 in comparison with the base case for the flow range of $F_1 \leq 4.8$. It reduces the average values of L_j/y_1 by about 29% for $F_1 \leq 4.8$.

Figure (5) shows the relations between F_1 and the discharge coefficient C_d for the different values of H/y_2. The case of H/y_1 = 0.798 gives the maximum values of C_d in comparison with the case of base case. It increases the average values of C_d by about 8.7%.

As seen in the experimental results, the jump characteristics have been improved as the relative vertical location of the circular opening; H/y_1 decreased. Actually, the minimum value of the relative vertical location of the circular opening; H/y_1 = 0.798 gives the best values of the relative jump depth y_2/y_1; the relative jump length L_j/y_1 and the relative energy loss $\Delta E/E_1$. In other words, as the circular opening becomes closer to the edge of the gate's edge as the, the jump characteristics become better.

5.2 Effect of Vertical Location of Circular Opening

The relations between the initial Froude number; F_1 and the different relative jump characteristics for the different relative diameter of the circular opening; (D/y_1 = 0.63; 0.93; 1.133 and 1.25) in case of (H/y_1 = 2.39, L/y_1 = 0 and θ = 0°) are shown in figure (6a, 6b, and 6c). Figures 6a, 6b and 6c show the relation of F_1 versus y_1/y_2, L_j/y_1 and $\Delta E/E_1$; respectively for different D/y_1 and the case of the standard sluice gate without any modifications. In addition, Fig. 7 shows the relation of F_1 versus C_d for different values of D/y_1.

It clears that the values of coefficient of discharge and the relative jump characteristics including y_2/y_1, L_j/y_1 and $\Delta E/E_1$ increase with the increase of the initial F_1. It can be seen that, the case of D/y_1 = 1.25 gives the minimum values of y_2/y_1, L_j/y_1.

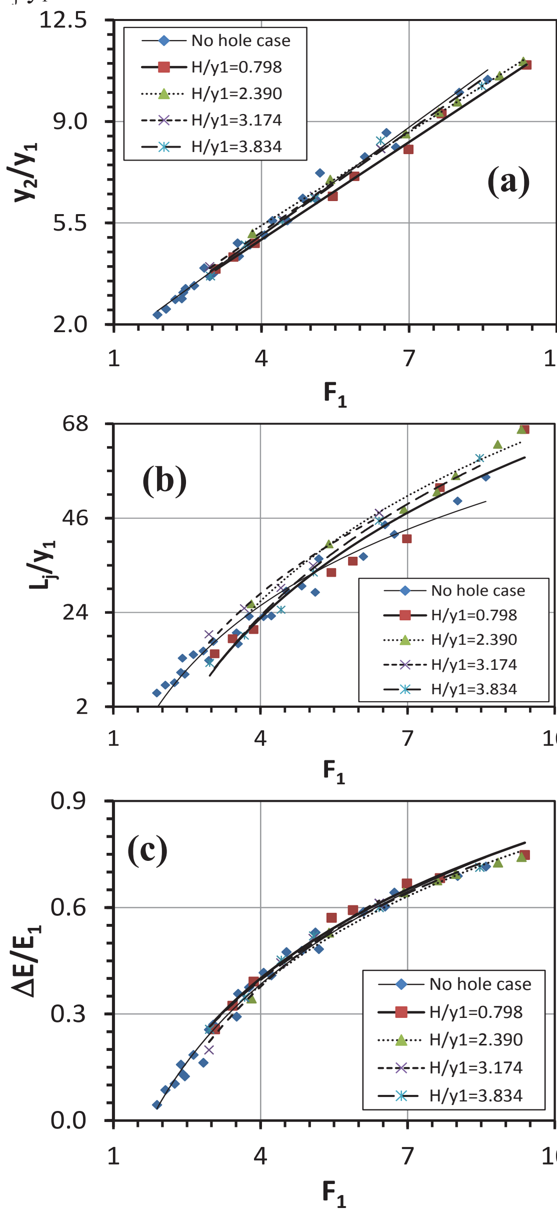


Figure (4): Relations between F_1 and jump characteristics for the different H/y_1 and (D/y_1 = 0.6, L/y_1 = 0.0 and θ =0°) [a] y_2/y_1; [b] L_j/y_1 [c] $\Delta E/E_1$

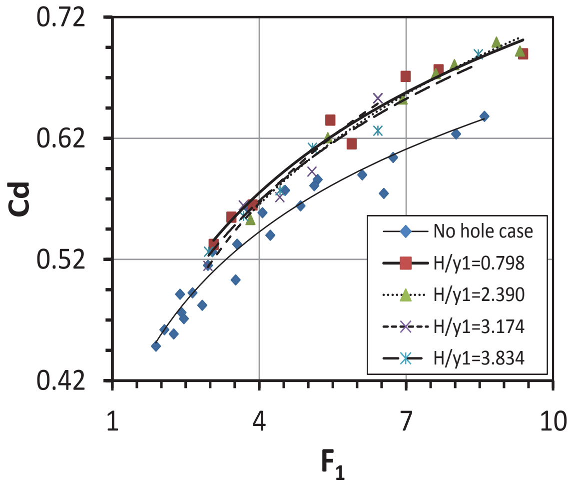


Figure (5): Relations between F_1 and C_d for the different H/y_1 and (D/y_1 = 0.6, L/y_1 = 0.0 and θ = 90°)

In contrast, it gives the maximum values of C_d and $\Delta E/E_1$.

The case of sluice gate of an opening with the circular opening of relative diameter of D/y_1 = 1.25 reduces the y_2/y_1, L_j/y_1 by 10.3% and 14.7%, respectively. In addition, it increases the average relative energy loss of the jump $\Delta E/E_1$ and C_d by 9% and 17.5%, respectively. Actually, the increasing of the relative diameter in the range of (0.93-1.25) improve the relative free jump characteristics and coefficient of discharge.

5.3 Effect of Hose Length Fitted at Circular Opening

In this stage, the effect of the relative length of rigid plastic hose fixed at the end of the circular opening perforated in the sluice gate L/y_1 is investigated experimentally.

The relations between the initial Froude number; F_1 and each of y_2/y_1; L_j/y_1; $\Delta E/E_1$ and C_d for different relative length of rigid plastic hose; (L/y_1 = 0.0, 1.233, 2.876 and 3.698) in case of (H/y_1 = 2.39, D/y_1 = 1.25 and θ = 90°) are shown in figures (8a, 8b, 8c and 9). It clears that, the case of L/y_1 = 0.0 gives the minimum values of y_2/y_1, L_j/y_1. In contrast, it gives the maximum values of C_d and $\Delta E/E_1$. The case of L/y_1 = 0.0 reduces y_2/y_1, and L_j/y_1 by 10.3% and 14.7%. In addition, $\Delta E/E_1$ and C_d by 9% and 17.5%, respectively.

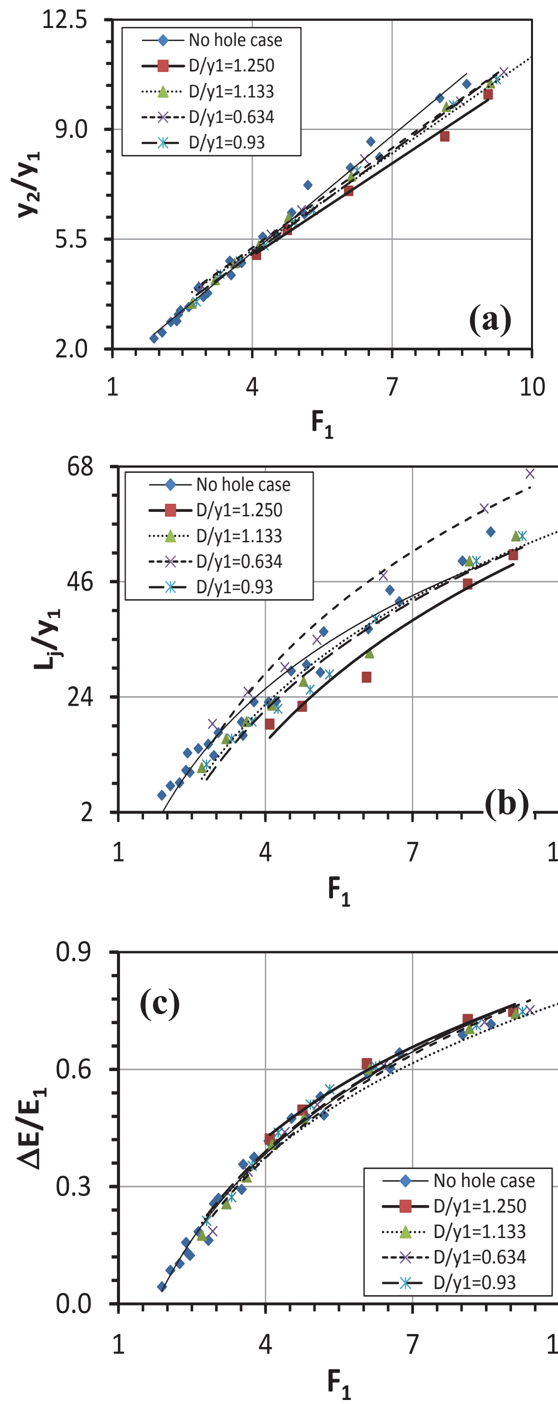


Figure (6): Relations between F_1 and jump characteristics for the different D/y_1 [a] y_2/y_1;

5.4 Effect of Hose Angle Fitted at Circular Opening

In this stage, the effect of the angle of inclination of the hose fixed at the sluice gate, θ is investigated experimentally. The relations between the initial Froude number; F_1 and each of y_2/y_1; L_j/y_1; $\Delta E/E_1$ and C_d for the different angles of inclination of the hose; (θ = 60°, 90°, 120° and 150°) in case of (H/y_1 = 2.39, D/y_1 = 1.25 and L/y_1 = 2.876) are shown in figures (10a, 10b, 10c and 11).

It clears that, the case of θ= 150° gives acceptable values of y_2/y_1, L_j/y_1. In contrast, it gives the maximum values of C_d and $\Delta E/E_1$.

The case of 150° reduces the y_2/y_1, L_j/y_1 by 12.3% and 29%. In addition, it increases the average values of $\Delta E/E_1$ and C_d by 8% and 16.5%, respectively.

6. STATISTICAL REGRESSION

The statistical analysis was used to relate the dependent parameters including y_1/y_2, L_j/y_1; $\Delta E/E_1$; and C_d and other independent ones under the basis of non-liner regression. The best equations predicting each of the relative jump depth y_2/y_1; the relative jump length L_j/y_1; the relative energy loss $\Delta E/E_1$ and the coefficient of the discharge C_d for all experimental measurements can be given by the following forms.

Figures (12a, 13a, 14a and 15a) show a comparison between the measured y_1/y_2, L_j/y_1; $\Delta E/E_1$; and C_d and the predicted ones using statistical models Equations 18, 19, 20 and 21), respectively for all experimental measurements. The visual comparison indicated an acceptable agreement between the model prediction and experimental data. R^2 = 0.993, 0.93, 0.96 and 0.97, respectively. The value of R^2 for equation 19 is less than the other equations, but it is still acceptable. The residuals of the previous equations are plotted versus the predicted values as shown in Figs(12b, 13b, 14b and 15b). R^2 = 0.006, 0.07, 0.038 and 0.028, respectively. The values are less than 7%, which can be accepted. The residuals show random distribution around the line of zero for equation (18, 19 and 21). Actually, the final decision is mainly depends the values of R^2.

The equations were built depending upon the available data, it may need more experimental measurements. However, the application of the developed equations in the field needs more modifications and calibrations. Actually, it needs more experimental works before the stage of field applications.

The limitations of the developed equations are presented in table (2). The water depth upstream the gate should not exceed twice the gate opening.

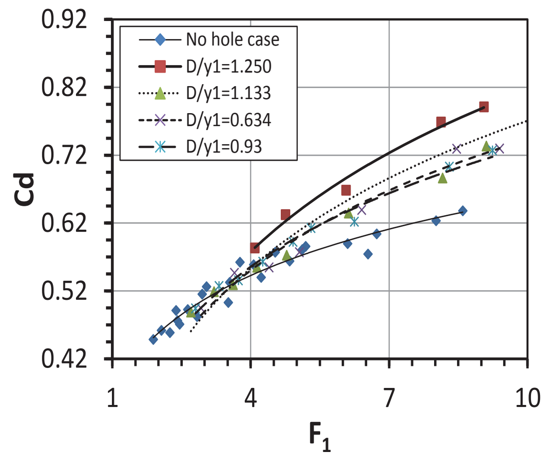
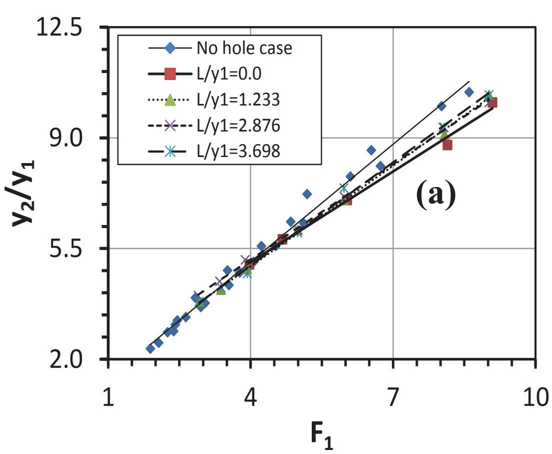


Figure (7): Relations between F_1 and C_d for the different D/y_1 and (H/y_1 = 2.39, L/y_1 = 0 and θ = 90°)



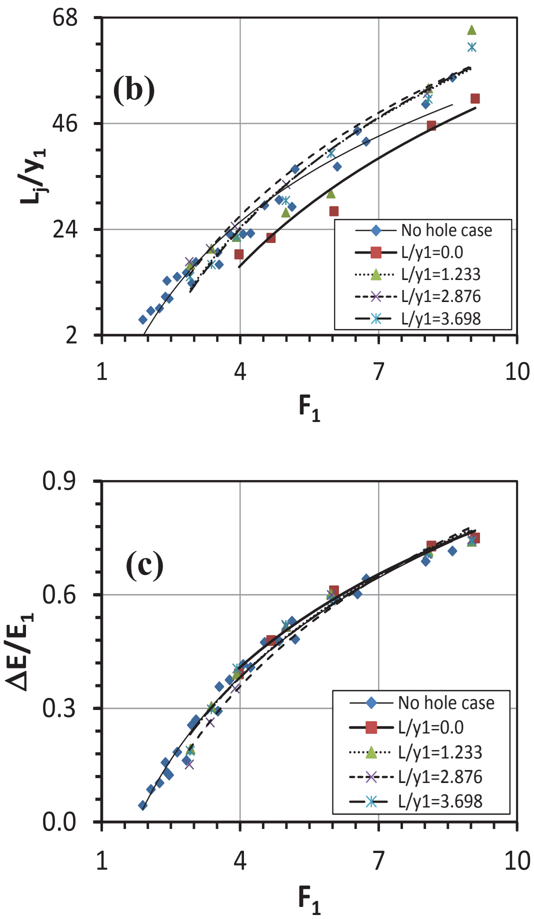


Figure (8): Relations between F_1 and jump characteristics for the different L/y_1 and ($H/y_1 = 2.39$, $D/y_1 = 1.25$ and $\theta = 90^o$) [a] y_2/y_1; [b] L_j/y_1 [c] $\Delta E/E_1$

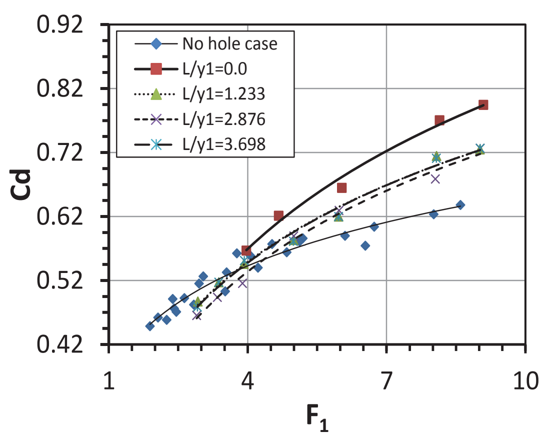


Figure (9): Relations between F_1 and C_d for the different L/y_1 and ($H/y_1 = 2.39$, $D/y_1 = 1.25$ and $\theta = 90^o$)

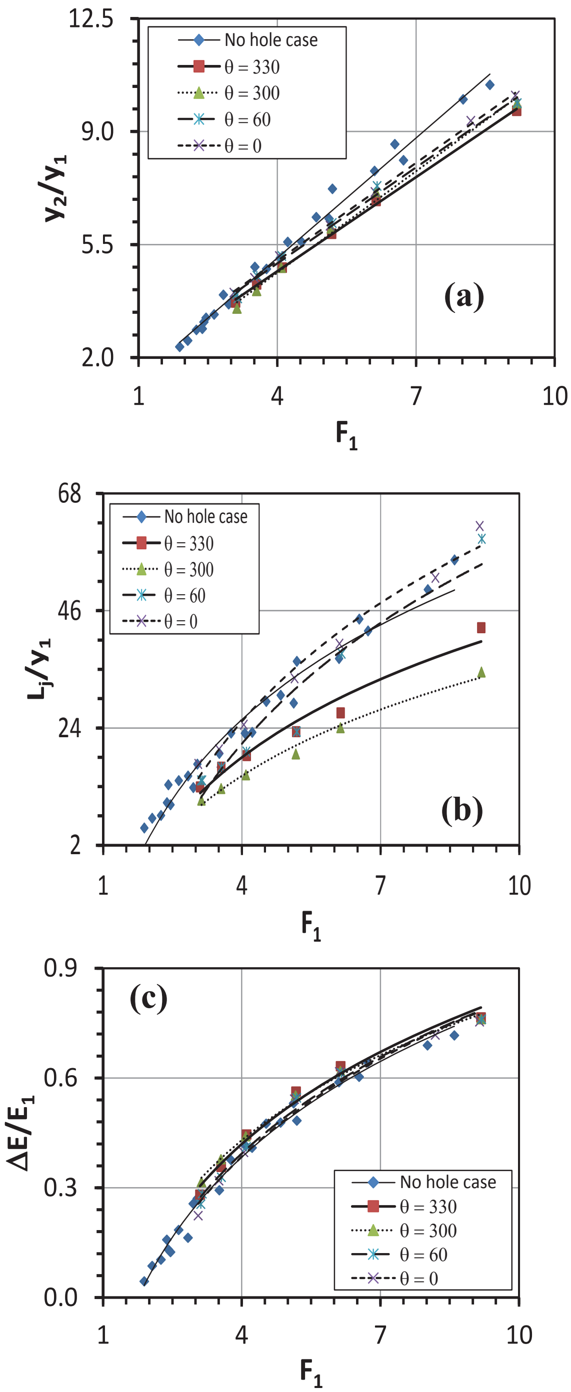


Figure (10): Relations between F_1 and jump characteristics for the different θ and ($H/y_1 = 2.39$, $D/y_1 = 1.25$ and $L/y_1 = 2.876$) [a] y_2/y_1; [b] L_j/y_1 [c] $\Delta E/E_1$

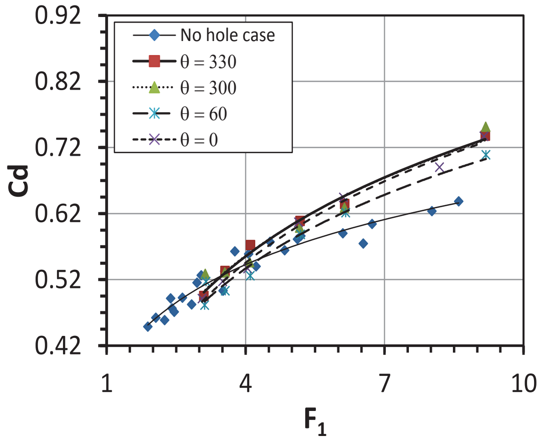


Figure (11): Relations between F_1 and C_d for the different θ and (H/y_1 = 2.39, D/y_1 = 1.25 and L/y_1 = 2.876)

Table (1): limits of developed equations

	Characteristics			
	H/y_1	D/y_1	L/y_1	q (degree)
The lower range	0.78	0.63	0	0
The upper range	3.84	1.25	3.69	330

Finally, it can be said that the equations may be.

$$\frac{y_2}{y_1} = -0.769 + \frac{0.05H}{y_1} - \frac{0.184D}{y_1} - \frac{0.077L}{y_1} + 0.1\sin\theta + 2.98\log(\frac{H_{up}}{y_1}) + 0.763F_1 \quad (18)$$

$$\frac{L_j}{y_1} = -17.36 + \frac{1.63H}{y_1} - \frac{5.12D}{y_1} - \frac{0.24L}{y_1} + 4.4\sin\theta + 24.46\log(\frac{H_{up}}{y_1}) + 4.36F_1 \quad (19)$$

$$\frac{\Delta E}{E_1} = -0.337 - \frac{0.001H}{y_1} + \frac{0.03D}{y_1} - \frac{0.003L}{y_1} - 0.021\sin\theta + 0.69\log(\frac{H_{up}}{y_1}) + 0.007F_1 \quad (20)$$

$$C_d = 0.329 + \frac{0.005H}{y_1} + \frac{0.0003D}{y_1} - \frac{0.0029L}{y_1} - 0.0028\sin\theta - \frac{0.014H_{up}}{y_1} + 0.088F_1 \quad (21)$$

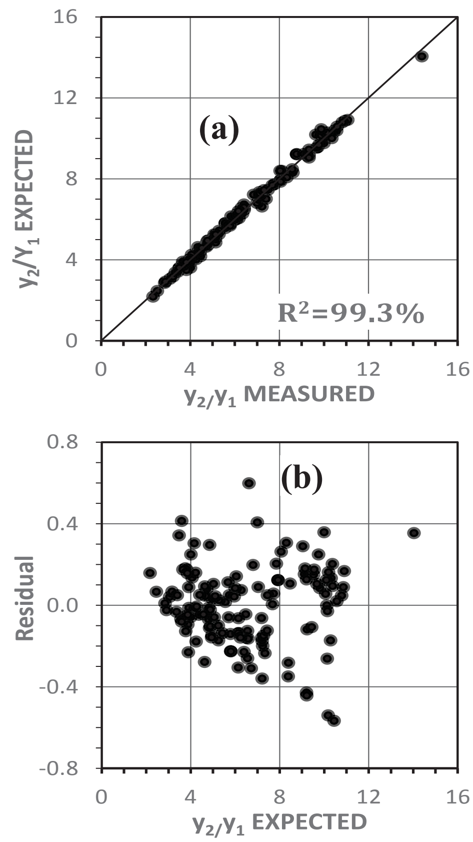


Figure (12): (a) relation between the measured y_2/y_1 and the predicted ones (b) Variations of residuals for different data sets with predicted data Eq. (18)

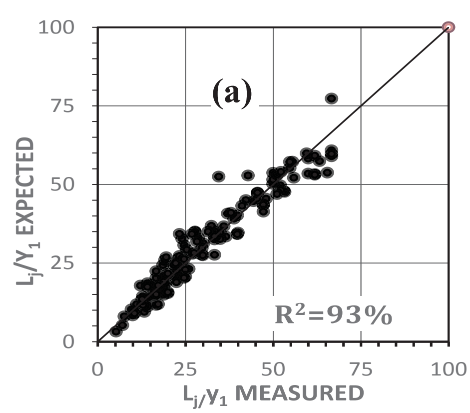


Figure (13a)

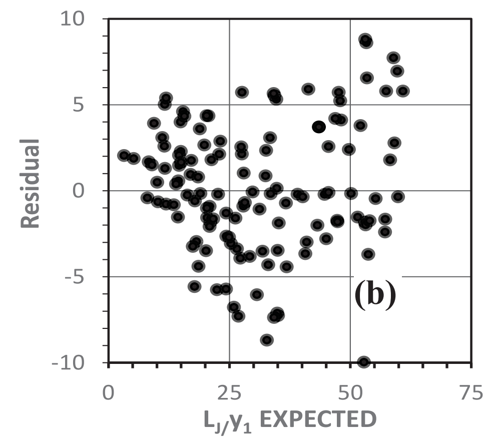


Figure (13): (a) relation between the measured Lj/y_1 and the predicted ones (b) Variations of residuals for different data sets with predicted data Eq. (19)

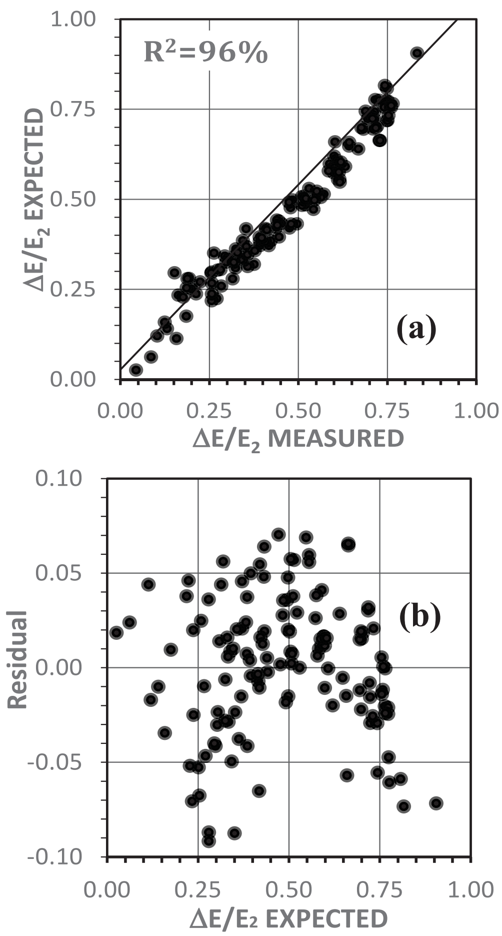


Figure (14): (a) relation between the measured $\Delta E/E_1$ and the predicted ones (b) Variations of residuals for different data sets with predicted data Eq. (20)

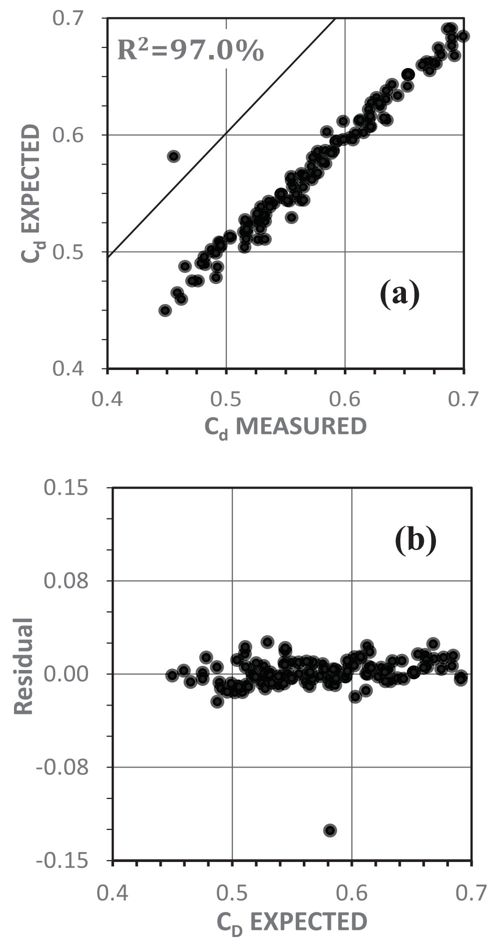


Figure (15): (a) relation between the measured C_d and the predicted ones (b) Variations of residuals for different data sets with predicted data Eq. (21)

7. CONCLUSIONS

The experimental work was accompanied to study characteristics of flow through gate with an opening. It investigated the effect of the diameter and location of the opening on the characteristics of the hydraulic jump formed downstream the gate. In addition, the effect of the length and angle of inclination of a pipe fixed to the opening was investigated. The following conclusions can be listed.

– The developed theoretical equations prove an acceptable agreement as compared to the experimental results. The minimal value of the achieved R^2 is 88.9%,

– The relative vertical location of the circular opening; H/y_1 = 0.798 reduces the average values of y_2/y_1 by about 9%, it increases the lost energy by about 7%. Moreover, it reduces the values of L_j/y_1 for the flow range of $F_1 \leq 4.8$ by about 29%. The case of H/y_1 = 0.798 increases the average values of C_d by about 8.7%,

– The case of sluice gate with a circular opening of relative diameter of D/y_1 =1.25 reduces the y_2/y_1, L_j/y_1 by 10.3% and 14.7%, respectively. In addition, it increases the average relative energy loss of the jump $\Delta E/E_1$ and the coefficient of discharge C_d by 9% and 17.5%, respectively,

– The case of L/y_1 = 0.0 reduces y_2/y_1, L_j/y_1 by 10.3% and 14.7%%, respectively. Also, it increases the average values of $\Delta E/E_1$ and C_d by 9% and 17.5%, respectively,

– The case of sluice gate with a circular opening and plastic hose of angle of inclination 330^o reduces the y_2/y_1, L_j/y_1 by 12.3% and 29%, respectively. In addition, it increases $\Delta E/E_1$ and C_d by 8% and 16.5%, respectively, and

–The comparison between the measurements and the statistical equations

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