ISSN: 1687-1006 p
ISSN: 2682-3640 e

The Egyptian International Journal of Engineering Sciences and Technology

Vol. 38 (2022) 1–10

https://eijest.journals.ekb.eg/

Effect of double gate mechanism on scour hole characteristics

Gamal Abdelaal[a], Asmaa Basyoni[b*], Eman A. Elnikhely[a]

[a] *Water and Water Structure Engineering Department, Faculty of Engineering, Zagazig University, Zagazig, Egypt, Zagazig 44519, Egypt*
[b] *The Expansion Sector, Ministry of Water Resources and Irrigation, Zagazig 44519, Egypt*

ARTICLE INFO

Keywords:

Local scour
Vertical gates
Double gates
precaution plate
Hydraulic jump

ABSTRACT

Local scour due to free hydraulic jump downstream hydraulic structures may cause damage or complete failure of these structures, so controlling of this phenomenon is very important. The main goal of this study is to reduce the characteristics of a scour hole downstream double gates system. Using a plate in certain positions have to build downstream of the model as a typical engineering precautions to minimize the effect of erosion. The optimum precaution plate position is a key parameter in the design of this type of hydraulic structures. The proposed model of the double vertical gates distributed the passing discharge via two vents, in which the lower discharge passed under the lower gate, while the upper discharge was the passing discharge between the two vertical gates. Using the relative gate opening of 0.25 and fixing the plate at relative vertical position Z/L_B of 0.00, 0.027, 0.047 and 0.067. The plate at a relative vertical position of 0.067 was the optimal position causing an increasing of the relative energy loss by 1.72% and the relative maximum scour depth decreased by 1.69% compared to the case of no plate downstream the gates. The measured results matched closely with the estimated results from the developed empirical equations.

1. Introduction

Scour is a natural phenomenon caused by the flow of water over an erodible boundary. Flow through gates is a marvelous amount of potential energy, which is converted into kinetic energy downstream the hydraulic structures. This energy should be dissipated to prevent the possibility of excessive scouring of the downstream river bed, minimize erosion and the undermining of the structures, which endanger the structure safety.

Many studies take place to reduce maximum scour depth downstream hydraulic structure. The impact of grain size on a local channel scour below a submerged sluice gate were studied by **Kells, et al. [1]**. The maximum scour depth location measured from the upstream end of the movable sandy bed moved downstream with an increase in either the discharge ortailwater depth and upstream with an increase in the grain size. **Defina and Susin [2]** studied the behavior of the flow under a vertical sluice gate. Froud number of the induced hysteretic subcritical approaching flow was greater than that the supercritical flow by approximately 0.8. The effect of grain size was experimentally inconsidered by **Sarkar and Dey [3],** the characteristics of scour holes in uniform and nonuniform sediments downstream apron under the effect of a submerged horizontal jet released from a sluice opening. For uniform sediments, the maximum equilibrium scour depth increased with the increasing of the densimetric Froude number, whereas the dune height decreased with the increasing of the densimetric Froude number. In addition, for the nonuniform sediments, the length of the scour holes decreased with

*Corresponding author. Tel.: +201066375100, +201010832595
E-mail address: civilengineerasmaa@gmail.com

an increase in the geometric standard deviation of sediments.

Local scour is the removal of granular bed materials by the action of the hydrodynamic forces. **[4]**, proved that the relative sequent depth is a function of Froude number and the expansion ratio only. **[5]** presented formula for the relative sequent depth to abrupt enlargement case. **Hager [6]** studied the hydraulic jump in nonprismatic rectangular channels. The volume of the hydraulic jumps in rectangular horizontal channels dependent only on the inflow Froud number and the width ratio had no effect. Flow characteristics were experimentally investigated by **Yen, et al. [7],** the hydraulic characteristics and the discharge of sluice gates were also investigated. The distinguishing conditions of free flow and submerged flow were a function of the contraction coefficient, upstream water depth and tailwater depth. **Kim [8]** analysied numerically the free flow past a sluice gate using the Reynolds averaging Navier-Stokes equations to calculate the contraction and the discharge coefficients and the pressure distribution.

The submerged hydraulic jump was experimentally investigated by **Negm, et al. [9]** studied the effect of multi-gates regultators operations on the downstream scour pattern under submerged flow conditions. The maximum scour depth was a function of the near bed velocity pattern, operation of gates, type of gates (i.e., main or emergency), Froude number at the vena contracta and submergence ratio. Experimental investigation was performed by **Ali, et al. [10]** to study the effect of using varied spaced corrugated aprons on the downstream local scour.

Local scour downstream sluice gates investigated experimentally by **Chatterjee, et al. [11] and Abdel-Rahim [12]** using a solid bed followed by an erodible basin. The minimum length of the rigid apron to prevent scour was greater than the sum of the rigid apron and scour hole lengths. **Lim and Yu [13]** investigated a scour downstream a sluice gate without fixed beds. The maximum brink scour depth of the downstream apron was 0.44 times the maximum scour depth. **Abdel-Aal, et al. [14]** investigated experimentally the effect of side slopes of a trapezoidal channel on a maximum scour depth downstream transition sections. The cross section side slope of 0.35:1 with presence of guide walls reduced the relative scour parameters. **Negm, et al. [15]** investigated the optimal position of a curved deflector to minimize a scour downstream multi-vent regulators. The curved deflector reduced the local scour by 85%. Local scour characteristics behind sluice gates were experimentally investigated by **Abdel-Aal, et al. [16]**, the optimal expansion ratio was 1.5.

The time scour term was incosiderated by **Uyumaz [17],** the scour downstream a vertical gate of a river in which peak flows occurred for a short duration. The time history of a scour development was of major importance. **Mohamed and McCorquodale [18]** studied short term local scour downstream the apron with a swept-out hydraulic jump, the local scour developed very rapidly. Identifying the worst scour conditions was investigated by **Champagne, et al. [19] and Champagne, et al. [20]** the downward plunging flow during leaving the stilling basin induced the primary scour hole. The worst flow condition for a scour was the uncontrolled free flow with high headwater and low tail water below the spillway crest. A scour induced by flow patterns at a gated weir stilling basin was studied experimentally by **Shahabi, et al. [21]** the effect of contraction on a scour characteristics downstream the combined flow over and below gate. The maximum scour depth of a combined flow was less than that of the individual cases (i.e., over flow and below the gate).

Flow through free double baffled gates in vertical direction were studied by **[22]** Investigated experimentally scour of a cohesionless bed downstream of an apron due to submerged jet without apron completely over, and completely below a vertical gate. He draw The maximum depth and location of scour, volume of scour, volume of dune, and scour profiles under two situations at different discharges. He found that the maximum depth increases with increase in discharge and volume of scour increases with increase in discharge per unit width of channel in each situation. However, the depth of scour hole, dune height, volume of scour, extent of scour, and dune are maximum, when flow is completely above the gate and minimum when completely below the gate. [23] Presents an experimental investigation and numerical analysis of the flow through the free double baffled gate. It was found that the gate inclination angle (α) and the gate spacing (S) are the most effective parameters in controlling the H-Q relation, where (Q is the discharge throughout the gate and H is the upstream head of the gate measured vertically from the crest (in the case of pure weir flow). The optimum value of α is about 30^o, and of the gate spacing (S) is 60 to 70% of the gate opening. **Abdel-Aal, et al. [24]** studied the free jump parameters under the effect of two vertical overlapping gates (TVOG). Working the TVOG by upper opening by 50% of the lower one dissipated the flow energy by 52% and shrinked the basin length by 4.3%.

From the previous review, it can be concluded that there are many published papers related to the flow under a vertical sluice gate. However, there are limited studies dealt with local scour downstream the double gates system. Thus, the main objective of this study is to investigate the optimal relative gate opening inducing the minimum relative maximum scour depth and maximum energy dissipation.

2. Dimensional analysis

Figure 1 shows a schematic sketch of the prposed system of double vertical gates using adownstream plate as precaution indicating the effective parameters acting on the scour hole dimensions. The dimensional analysis based on Buckingham theory was used to develop a functional relationship between the maximum scour depth and the other variables as indicated in Eq. 1. The maximum scour depth (Ds) downstream stilling basins can be defined as follows:

$$D_s = f\begin{pmatrix} b, B, D_{50}, D_d, G_1, G_2, g, \Delta E, E_{1,} L_B, \\ X, th, Z, L_s, L_d, T_{j,} v_{1,} Y_1, Y_2, \rho, \rho_s \end{pmatrix} \qquad \text{Eq. (1)}$$

Through this study, these parameters b, B, D_{50}, g, th, X and ρ_s are kept constants. By applying the Buckingham theorey with ρ, Y_1, v_1 as repeating variables. Thus, Eq. (1) can be written in a dimensionless form as shown in Eq. (2).

$$\frac{D_S}{Y_1}, \frac{L_S}{Y_1}, \frac{D_d}{Y_1}, \frac{L_d}{Y_1}, \frac{Y_2}{Y_1}, \frac{\Delta E}{E_1} = f(F1, \frac{G_2}{G_1}, \frac{Z}{L_B}) \qquad \text{Eq. (2)}$$

In which, D_s/Y_1 is the relative maximum scour depth, D_d/Y_1 is the relative maximum deposition depth, F_1 is the initial Froude number, Y_2/Y_1 is the relative sequant depth of the hydraulic jump, $\Delta E/E_1$ is the relative energy loss, G_2/G_1 is the relative gate opening, l_j/Y_1 is the relative length of the hydraulic jump and Z/L_B is the relative vertical position of the downstream plate.

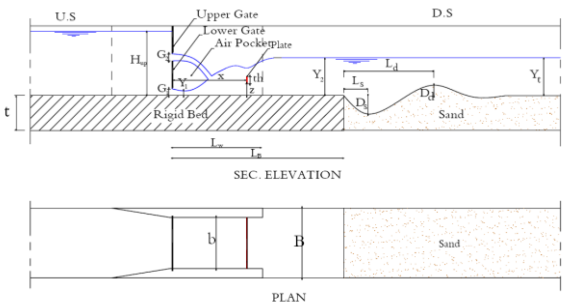


Figure 1 Schematic sketch for the experimental model.

3. Experimental set up

Experimental realization were executed in the water and hydraulics engineering laboratory of the Faculty of Engineering, Zagazig University, Egypt. A rectangular re-circulating flume of 0.298 m width, 0.486 m height and 15.6 m length is equipped with a tailgate to control the tail water depth. The discharges were measured by using a pre-calibrated orifice meter fixed in the feeding pipeline. A point gauge was used on the carriage to measure both the water levels and bed deformations in the longitudinal and transverse directions of the channel with an accuracy of ±0.1 mm. A system of douple vertical sluice gates made from Perspex of thickness 10 mm sliding through two vertical grooves was designed and fixed in two woody abutments of 40 cm length. The wood was painted very well by anti water material to prevent wood from changing its volume by absorbing water. A plate of thickness 3cm was fixed downstream the gates with varied horizontal distance and at afixed vertical distance of 5 cm.

The distance from the sluice gate to the end of the downstream apron is 74 cm. A coarse sand with length 6 m, 15cm depth and the mean diameter D_{50} = 0.48 mm was used as a movable bed.

Thirty-five runs were conducted throughout the experimental program of this study and categeorized into five sets. Each run lasted about 2 hours. The first set included the measurements of scour parameters and flow characteristics in the case of operating the downstream plate with relative horizontal distance of X/L_B = 0.14, 0.27, 0.40 , 0.54 and without using the downstream plate that was used a reference case to estimate the influence of using the proposed positon of the downstream percauton plate, all this cases at relative gate opening equal 0.25.

4. Results and discussion

The data was divided into two portions. The first one is 80% for the estimation of the regression coeffecients, while the remaining 20% was used testing the developed equation.

4.1. Hydraulic Jump Characteristcs and Scour parameters downstream the double gate system of G_2/G_1= 0.25 with and without using downstream plate.

The hydraulic jump characteristics and the scour hole parameters have been investigated and figured against the initial Froude number F_1 for cases of using downstream plate of Z/L_B of 0.00, 0.027, 0.047 and 0.067 and without using downstream plate for the relative horizontal distance of X/L_B = 0.27, relative plate thickness th/L_B = 0.04 and relative gate openings G_2/G_1 = 0.25.

The parameters included the relative sequent depth of the hydraulic jump Y_2/Y_1, the relative energy loss $\Delta E/E_1$ the maximum relative scour depth, D_s/Y_1, the relative scour length L_s/Y_1, the maximum relative deposition depth D_d/Y_1 and the relative deposition length L_d/Y_1

4.1.1 Hydraulic Jump Characteristcs downstream the double gate system of G_2/G_1= 0.25 with and without using downstream plate.

The effect of the double vertical gates on the characteristics of the hydraulic jump for the considered G_2/G_1 were presented in Figure 2 to Figure 7. The hydraulic jump characteristic Y_2/Y_1 and $\Delta E/E_1$ increased as the F_1 increased and directed proportionally for different relative plate vertical position.

Figure 2 indicated the relation of Y_2/Y_1 with F_1 for the considered G_2/G_1 of 0.25 of the double gate system with and without using downstream plate. At the relative plate vertictal position of 0.067, the optimal values of Y_2/Y_1 were present. The relative sequant depth reached its minimum values at relative plate vertical position = 0.067 and exhibited a reduction in the Y_2/Y_1 of 17.95% compared to the case of without using downstream plate. On the other hand, relative plate vertical position equal 0.00, 0.027 and 0.047 cased variation on the relative sequant depth by 9.09%, -2.27% and 4.55% respectively compared to the case of without using downstream plate as appeared in Table 1.

Figure 3 showed the relation of $\Delta E/E_1$ and F_1 for the considered G_2/G_1 of 0.25 of the double gate system with and without using downstream plate. As the relative plate vertical position increased the $\Delta E/E_1$ also decreased at the same Froude number. The case of relative plate vertical position 0.067 revealed the maximum values of $\Delta E/E_1$ with respect to the case of without using downstream plate. A specified relative plate vertical position of 0.067 increased the relative energy loss by 1.72%, compared to the case of without using downstream plate. On the other hand, the plate relative vertical position of 0.00, 0.027 and 0.047 exhibited a reduction by 2.30%, 0.92% and 1.15% respectively, compared to without using downstream plate case as appeared in Table 1.

Table 1 Percentage of decrease in scour hole and energy characterstics due to different Cases of plate locations for various relative vertical positions at F_1 = 6.0 with respect to without using plate.

Case	Case (1)	Case (2)	Case (3)	Case (4)
Y_2/Y_1	9.09%	-2.27%	4.55	-17.95
$\Delta E/E_1$	-2.30%	-0.92%	-1.15%	1.72%
D_s/Y_1	35.59%	28.47%	62.03%	-1.69%
L_s/Y_1	44.77%	83.74%	211.80%	0.22%
D_d/Y_1	116.67%	123.33%	5.00%	-16.67%
L_d/Y_1	58.49%	47.17%	75.47%	7.55%

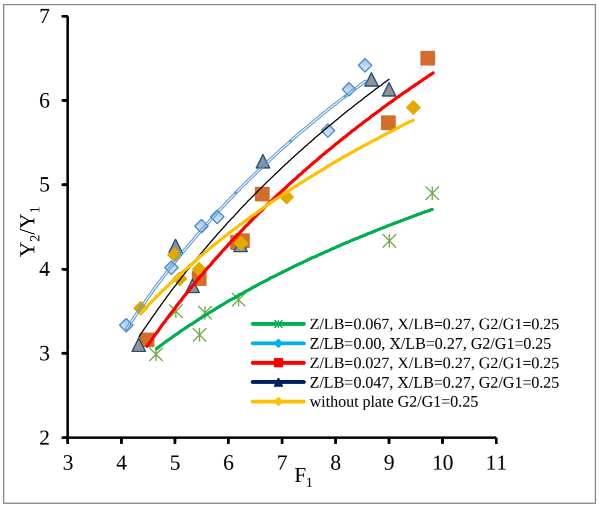


Figure 2 Relationship between Y_2/Y_1 and F_1 for G_2/G_1=0.25 without and with using downstream plate at various Z/L_B.

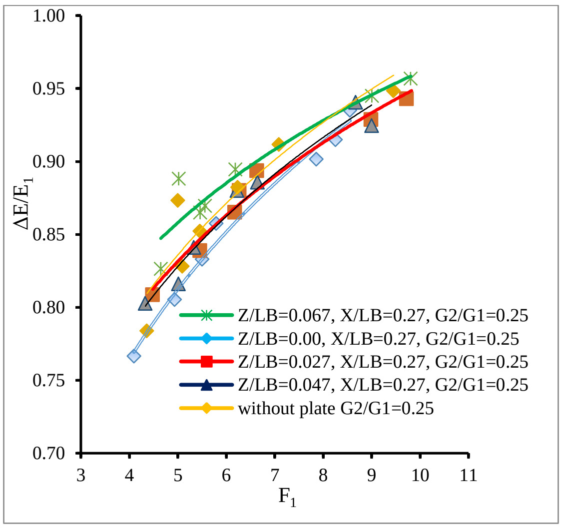


Figure 3 Relationship between $\Delta E/E_1$ and F_1 for G_2/G_1=0.25 without and with using downstream plate at various Z/L_B.

4.1.2 Scour parameters downstream the double gate system of G_2/G_1= 0.25 with and without using downstream plate.

Figure 4 showed the relationship of the relative maximum scour depth (D_s/Y_1) and initial Froude number (F_1) for different values of the relative plate vertical position (Z/L_B). The relative maximum scour depth was directly proportional to the initial Froude number for all relative plate vertical positions. As the Z/L_B increased the D_s/Y_1 also increased for the same Froude numbers except the case of Z/L_B = 0.067. The relative maximum scour depth reached its minimum values at Z/L_B = 0.067 with difference of 1.69% compared to the case of without using downstream plate. At froud number = 6.00, the specified plate relative vertical position of 0.00, 0.027 and 0.047 increased the D_s/Y_1 by 35.59%, 28.47% and 62.03% respectively, compared to the case of without using downstream plate as appeared in Table 1.

Figure 5 showed the relation of L_s/Y_1 and F_1 at different values of Z/L_B and the case of without using downstream plate. The relative scour length was directly proportional to the initial Froude number for all relative plate vertical positions. The values of the difference percentage of the L_s/Y_1 for different values of Z/L_B compared to the case of without using downstream plate were presented in Table 1. This table indicated that the relative deposition depth increased by 44.77%, 83.74%, 211.80 % and 0.22% related to without using downstream plate case in Z/L_B = 0.00, 0.027, 0.047 and 0.067 respectively for Froud number equal 6.00 as appeared in Table 1.

Figure 6 showed the relation of D_d/Y_1 and F_1 at different values of Z/L_B and the case of without using downstream plate. The D_d/Y_1 was directly proportional to the initial Froude number for all relative plate vertical positions. The case of Z/L_B = 0.067 produced the minimum values of D_d/Y_1 compared to the case of without using downstream plate. The values of the difference percentage of the D_d/Y_1 for different values of Z/L_B compared to the case of without using downstream plate were presented in Table 1. This table indicated that the relative deposition depth decreased by 16.67% in Z/L_B = 0.067 and increased by 116.67%, 123.33% and 5.00% related to without using downstream plate case in Z/L_B = 0.00, 0.027 and 0.047 respectively for Froud number equal 6.00 as appeared in Table 1.

Figure 7 showed the relation of L_d/Y_1 and F_1 at different values of Z/L_B and the case of without using downstream plate. The L_d/Y_1 was directly proportional to the initial Froude number for all relative plate vertical positions. The values of the difference percentage of the L_d/Y_1 for different values of Z/L_B compared to the case of without using downstream plate were presented in Table 1. This table indicated that the relative deposition depth increased by 58.49%, 47.17%, 75.47 % and 7.55% related to without using downstream plate case in Z/L_B = 0.00, 0.027, 0.047 and 0.067 respectively for Froud number equal 6.00 as appeared in Table 1.

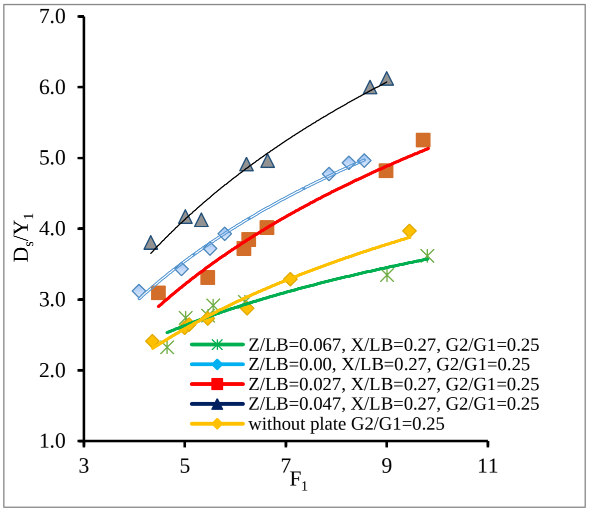


Figure 4 Relationship between D_s/Y_1 and F_1 for G_2/G_1=0.25 without and with using downstream plate at various Z/L_B.

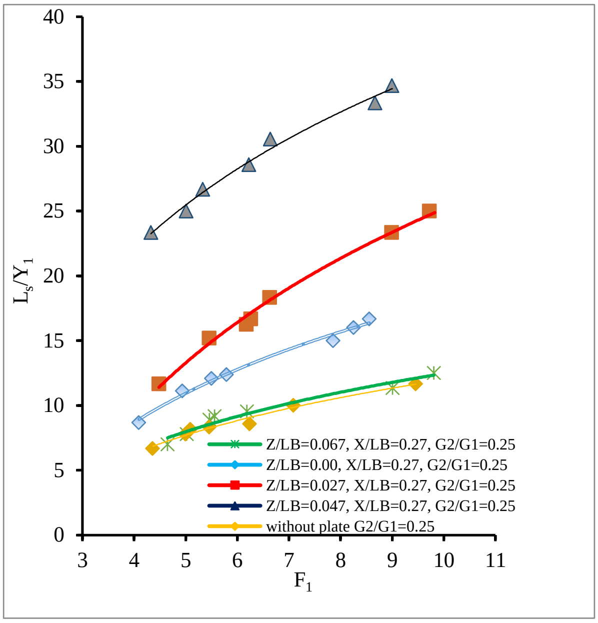


Figure 5 Relationship between L_s/Y_1 and F_1 for G_2/G_1=0.25 without and with using downstream plate at various Z/L_B.

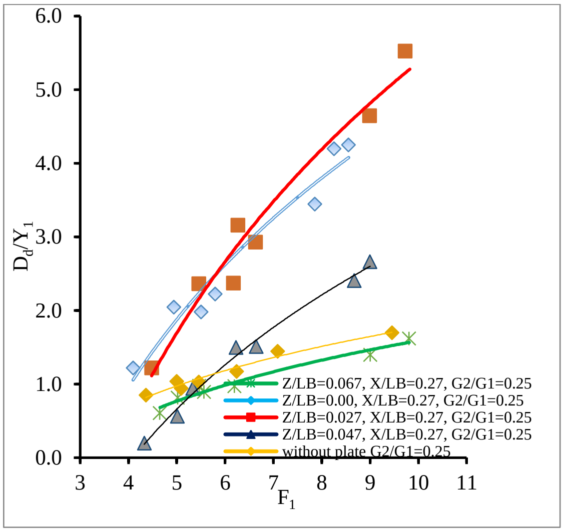


Figure 6 Relationship between D_d/Y_1 and F_1 for G_2/G_1=0.25 without and with using downstream plate at various Z/L_B.

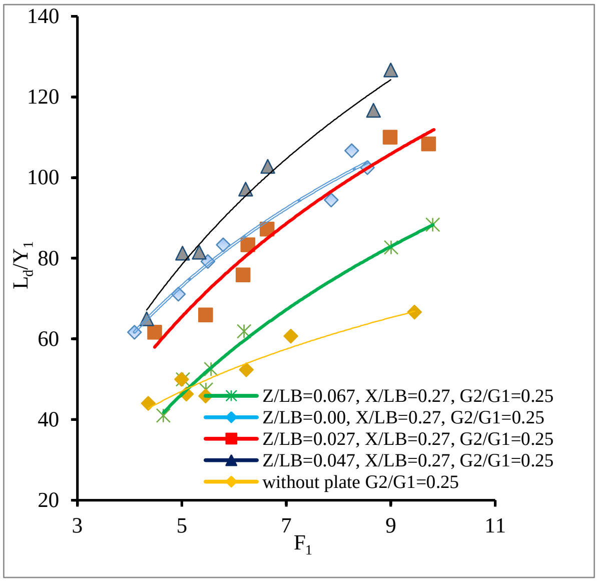
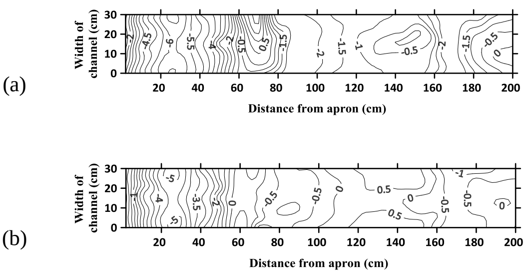


Figure 7 Relationship between L_d/Y_1 and F_1 for G_2/G_1=0.25 without and with using downstream plate at various Z/L_B.



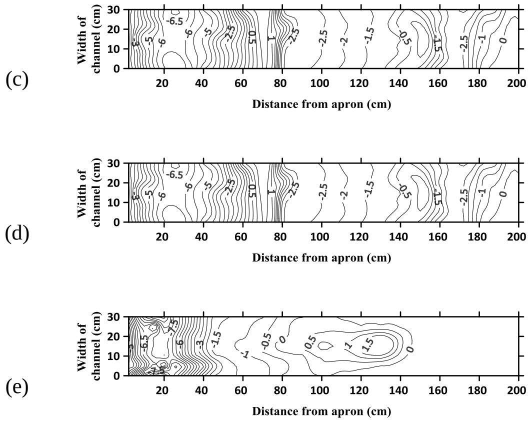


Figure 8 Scour contour maps for with various relative vertical position z/L_B = 0.00, 0.027, 0.047, 0.067 and without plate sequantly for G_2/G_1=0.25, a) G_1 = 4.50 cm, F_1=4.94 b) G_1 = 4.50 cm, F_1=5.46 c) G_1 = 4.50 cm, F_1=5.33 d) G_1 = 3.50 cm, F_1=5.16 e) G_1=4.5 and F_1=5.09.

4.2. Disscusion

From the figures 2, 3, 4, 5, 6 and 7 the value of Z/L_B = 0.067 showed the optimal position for the scour and energy parameters. Crossing of two jets and its location is issential for increasing or decreasing the scour process. When the plate location is far away from the gates, the two jets impacted the plate, thus extra energy can be dissipated at Z/L_B = 0.067 and hence the scour process decreased. When the plate moved near to the movable bed, the turbulance downstream the plate caused an increasing of the scour pramaters. As the plate moved near to the gates (i.e., Z/L_B < 0.067) the plate impacted only the lower jet, thus it dissipated lower energy than that in the case of Z/L_B = 0.067 and more than that of Z/L_B > 0.067, this can be attributed to the higher velocity of the lower jet.

For figure 12 in the case of lower gate only, the scour and depositions patterns seemed assymetric and the maximum scour hole was in the right side of the flume, while the maximum deposition was near to the left side at a distance 125 cm from the solid apron as shown in Figure 12. In the case of the double gate system, the bed deformation was nearly symetric.

4.3. Derivation of statistical equations

The following equations were proposed to predict the energy and the scour parameters Y_2/Y_1, $\Delta E/E_1$, D_s/Y_1, L_s/Y_1, D_d/Y_1 and L_d/Y_1 downstream double vertical gates in the vertical direction using statistical models were introduced in table 2 and a comparison between the measured and estimated data are presented in Figure 9.

$$\frac{Y_2}{Y_1} = 1.267 - 14.9743\frac{Z}{L_B} + 0.5785F_1 \qquad \text{Eq. (3)}$$

$$\frac{\Delta E}{E_1} = 0.674 + 0.492\frac{Z}{L_B} + 0.0285F_1 \qquad \text{Eq. (4)}$$

$$\frac{D_S}{Y_1} = 1.712 - 9.835\frac{Z}{L_B} + 0.4F_1 \qquad \text{Eq. (5)}$$

$$\frac{L_S}{Y_1} = -3.288 + 22.512\frac{Z}{L_B} + 2.0229F_1 \qquad \text{Eq. (6)}$$

$$\frac{D_d}{Y_1} = -0.66015 - 26.006\frac{Z}{L_B} + 0.5659F_1 \qquad \text{Eq. (7)}$$

$$\frac{L_d}{Y_1} = 26.117 - 249.12\frac{Z}{L_B} + 9.728F_1 \qquad \text{Eq. (8)}$$

Figure 9 shows a comparison between the measured and estimated values of Y_2/Y_1, $\Delta E/E_1$, D_s/Y_1, L_s/Y_1, D_d/Y_1 and L_d/Y_1 using Eqs. 3, 4, 5, 6, 7 and 8 respectively. The comparison showed good performance for all data and acceptable agreement was obtained. The regression statistics are shown in Table 2

Figure 10 shows a comparison between the measured and the predicted values of Y_2/Y_1, $\Delta E/E_1$, D_s/Y_1, L_s/Y_1, D_d/Y_1 and L_d/Y_1

Table 2 The regression statistics of Eqs. 3, 4, 5, 6, 7 and 8 respectively based on 80% of the measured data.

Regression Statistics	Eq. 3	Eq. 4	Eq. 5	Eq. 6	Eq. 7	Eq. 8
RMSE	0.413	0.0164	0.68	7.74	0.623	12.1663
R^2	0.8738	0.905	0.545	0.173	0.794	0.693

Table 3 Statistical parameters for Model Comparison.

Parameter	Name	Formula
Root Mean Square Error	RMSE	$\sqrt{\sum_i^j (Mes - Pre)^2/N}$
Coeff. of Determination	R^2	$\sum_i^j (Pre - avg.Mes)^2 / \sum_i^j (Mes - avg.Mes)^2$

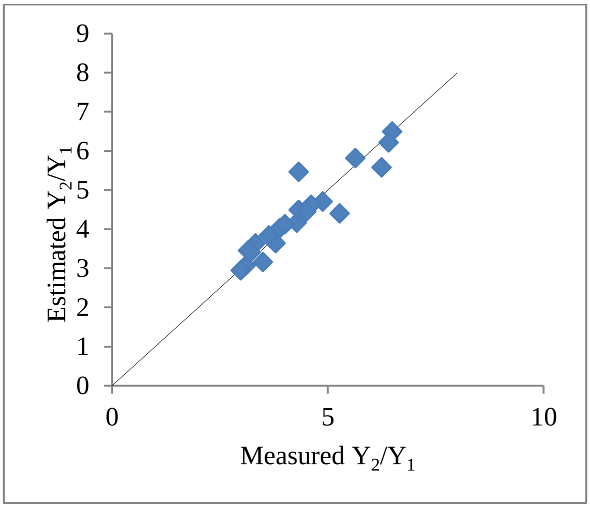


Figure9.a Comparison between measured and estimated data of Y_2/Y_1 using training data

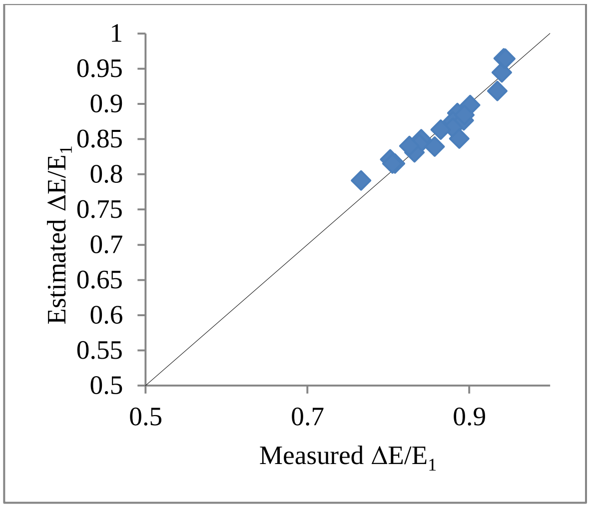


Figure 9.b Comparison between measured and estimated data of $\Delta E/E_1$ using training data

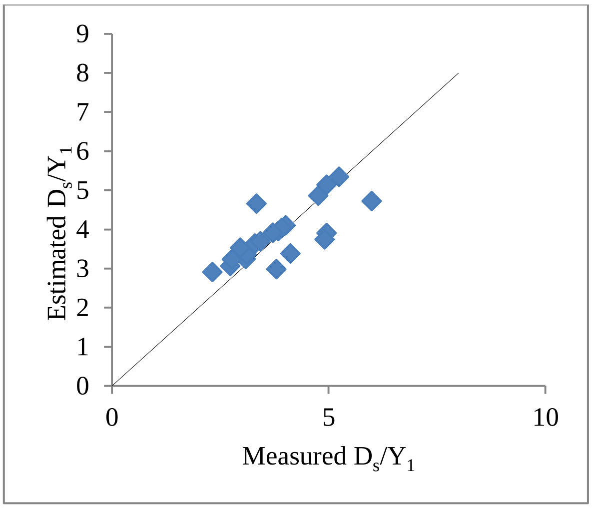


Figure 9.c Comparison between measured and estimated data of D_s/Y_1 using training data

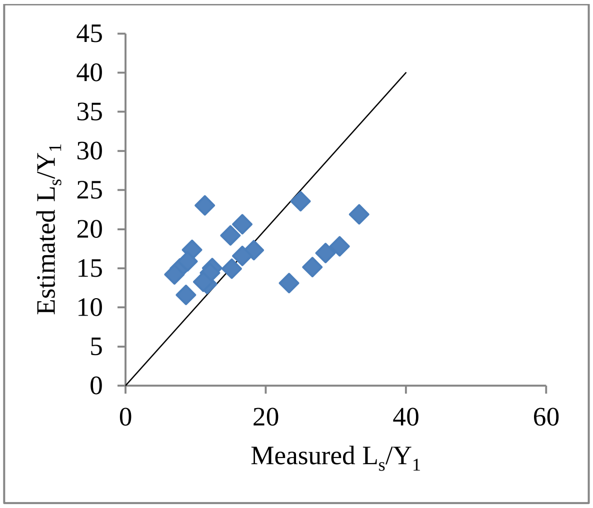


Figure 9.d Comparison between measured and estimated data of L_s/Y_1 using training data

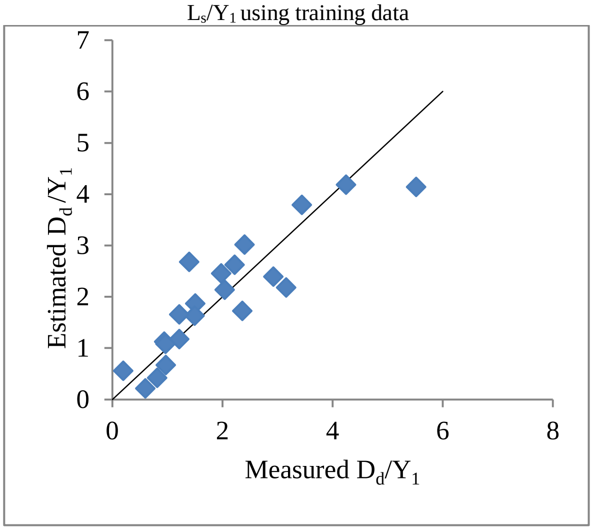


Figure 9.e Comparison between measured and estimated data of D_d/Y_1 using training data

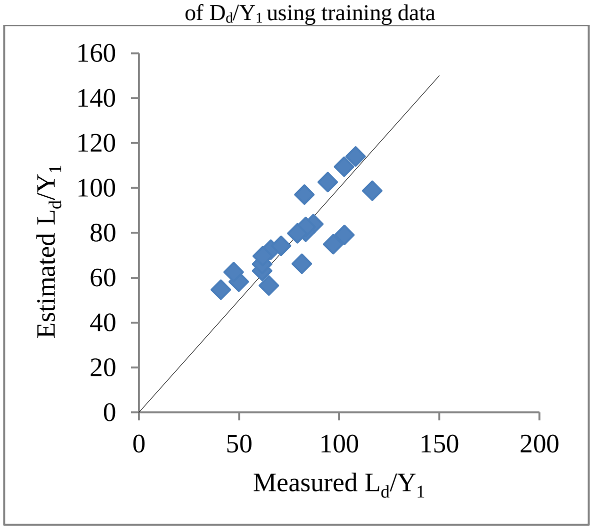


Figure 9.f Comparison between measured and estimated data of L_d/Y_1 using training data

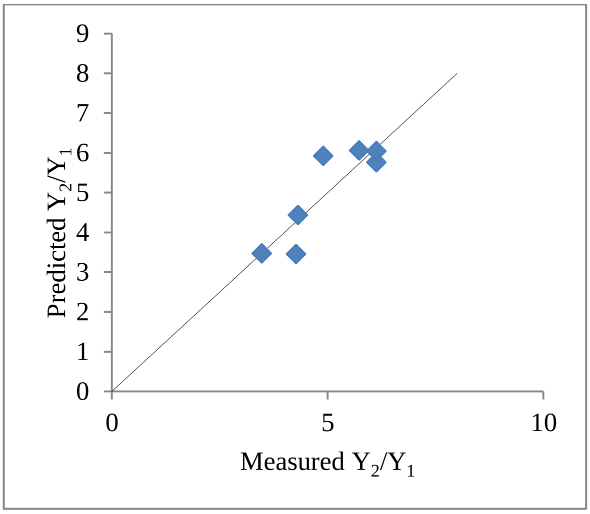


Figure 10.a Comparison between measured and predicted data of Y_2/Y_1 using testing data

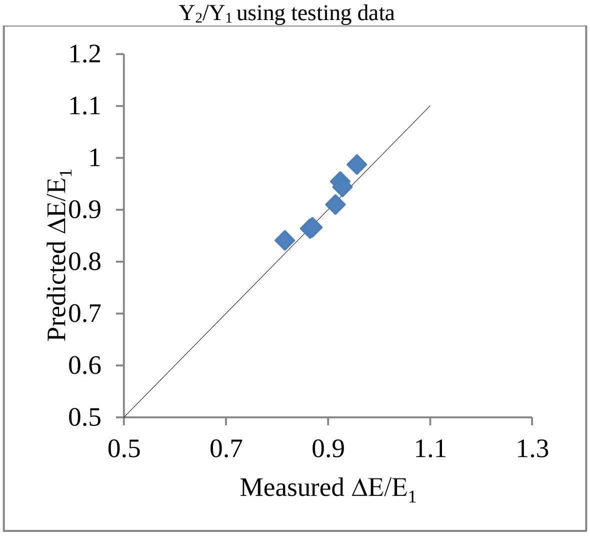


Figure 10.b Comparison between measured and predicted data of $\Delta E/E_1$ using testing data

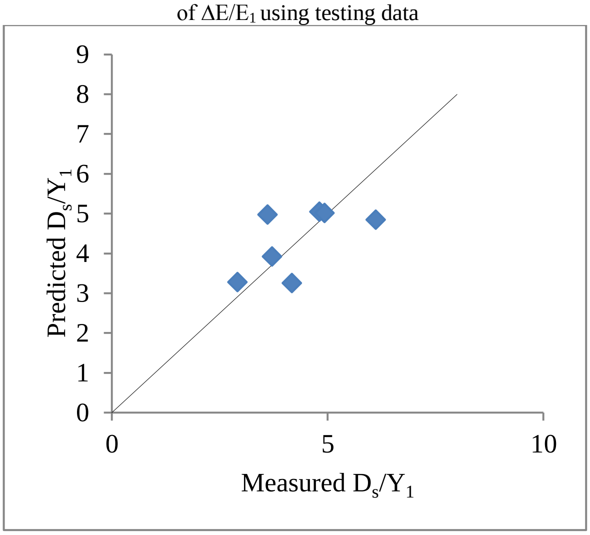


Figure 10.c Comparison between measured and predicted data of D_s/Y_1 using testing data

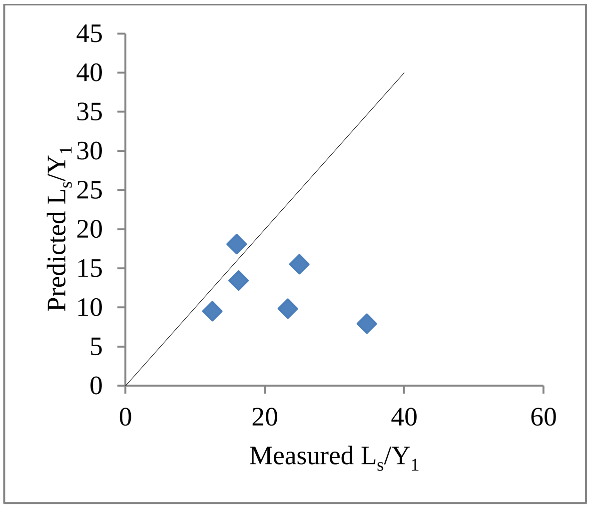


Figure 10.d Comparison between measured and predicted data of L_s/Y_1 using testing data

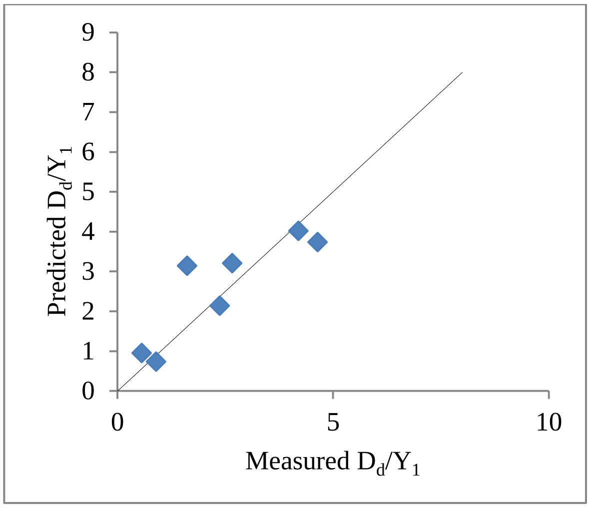


Figure 10.e Comparison between measured and predicted data of D_d/Y_1 using testing data

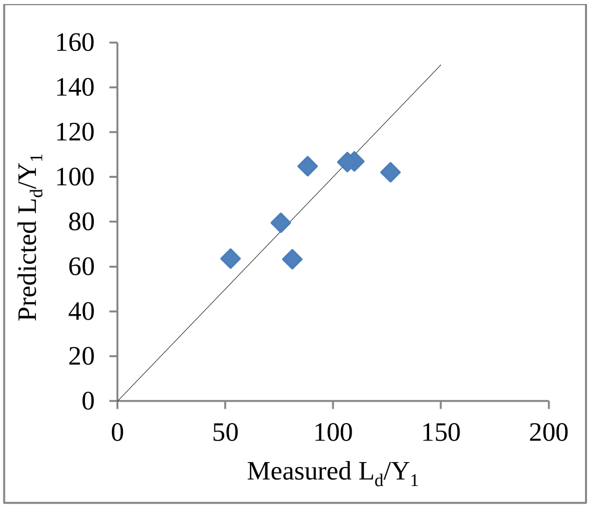


Figure 10.f Comparison between measured and predicted data of L_d/Y_1 using testing data

5. Conclusions

The changes of the local scour hole parameters and hydraulic jump characteristics due to the implementation of a double vertical gates system were studied with intial Froude number ranged from 4.36 to 9.8 for the relative gate opening of 0.25 and the plate relative vertical position of 0.00, 0.027, 0.047 and 0.067 for the relative horizontal distance of X/L_B = 0.27, relative plate thickness th/L_B = 0.04 and relative gate openings G_2/G_1 = 0.25 compared to the case of without using plate. Based on the experimental results, the conclusion were drawn as follow;

- The comparison of the relative maximum scour depth of the experimental work for the case of without using plate showed agood agreement.
- The plate relative vertical distance of 0.067 revealed the optimum values of the energy and the scour characteristics.
- The developed statistical equations showed a good agreement with the experimental measurements.

Notation

b	The gate opening width
B	The flume width
D_{50}	The mean diameter of the sand base
D_d	The maximum height of deposition
D_s	The maximum scour depth
e	Expansion ratio (B/b)
E_1	The energy at the beginning of the hydraulic jump
E_2	The energy at the end of the hydraulic jump
ΔE	Energy loss
F_1	The initial Froude number
g	The gravitational acceleration
G_1	Lower gate opening
G_2	Upper gate opening
G_2/G_1	Relative gate opening
H_{up}	The upstream water depth
L_w	The wing wall length
L_B	The apron length from the gate opening
L_j	jump length
L_s	Maximum scour length
L_d	Maximum deposition length
Q	The total discharge
RMSE	root mean square error
R^2	Coefficient of determination
th	The plate vertical thicknes
T_j	thickness of water jet of G2 at vana contracts
X	The plate horizontal distance from the gates
Y_1	The initial depth of hydraulic jump
Y_2	The sequent depth of hydraulic jump
Y_t	The tail water depth
Z	The plate vertical position from the apron

ρ The density of water

μ The dynamic viscosity of water

ρ_s The density of sand particles

References

[1] J. Kells, R. Balachandar, and K. Hagel, "Effect of grain size on local channel scour below a sluice gate," *Canadian Journal of Civil Engineering,* vol. 28, pp. 440-451, 2001.

[2] A. Defina and F. M. Susin, "Hysteretic behavior of the flow under a vertical sluice gate," *Physics of Fluids,* vol. 15, pp. 2541-2548, 2003.

[3] A. Sarkar and S. Dey, "Scour downstream of aprons caused by sluices," in *Proceedings of the Institution of Civil Engineers-Water Management*, 2005, pp. 55-64.

[4] N. Rajaratnam and K. Subramanya, "Hydraulic jumps below abrupt symmetrical expansions," *Journal of the Hydraulics Division,* vol. 94, pp. 481-504, 1968.

[5] K. Herbrand, "The spatial hydraulic jump," *Journal of Hydraulic Research,* vol. 11, pp. 205-218, 1973.

[6] W. Hager, "Hydraulic jump in non-prismatic rectangular channels," *Journal of Hydraulic Research,* vol. 23, pp. 21-35, 1985.

[7] J. F. Yen, C. H. Lin, and C. T. Tsai, "Hydraulic characteristics and discharge control of sluice gates," *Journal of the Chinese institute of engineers,* vol. 24, pp. 301-310, 2001.

[8] D.-G. Kim, "Numerical analysis of free flow past a sluice gate," *KSCE Journal of Civil Engineering,* vol. 11, pp. 127-132, 2007.

[9] A. Negm, G. Abdelaal, M. Elfiky, and Y. Abdalla, "Effect of multi-gates regulators operations on downstream scour pattern under submerged flow conditions," *Proc. IWTC11,* vol. 2, pp. 735-767, 2007.

[10] H. M. Ali, M. M. El Gendy, A. M. H. Mirdan, A. A. M. Ali, and F. S. F. Abdelhaleem, "Minimizing downstream scour due to submerged hydraulic jump using corrugated aprons," *Ain Shams Engineering Journal,* vol. 5, pp. 1059-1069, 2014.

[11] S. Chatterjee, S. Ghosh, and M. Chatterjee, "Local scour due to submerged horizontal jet," *Journal of Hydraulic Engineering,* vol. 120, pp. 973-992, 1994.

[12] G. A. Abdel-Rahim, "Estimation of the minimum floor length behind sluice gates against scour utilizing solid bed and erodible basin," *Journal of Engineering Science. Assiut University,* vol. 34, pp. 1159-1174, 2006.

[13] S.-Y. Lim and G. Yu, "Scouring downstream of sluice gate," in *First International Conference on Scour of Foundations. November 17-20, 2002, College Station, USA*, 2002, pp. 395-409.

[14] G. M. Abdel-Aal, A. M. Negm, T. M. Owais, and M. Shahin, "EFFECT OF SIDE SLOPES OF TRAPEZOIDAL CHANNEL ON MAXIMUM SCOUR DEPTH DOWNSTREAM OF TRANSITION," in *Proc., 9th Inter. Congress of Fluid Dynamics & Propulsion, Alex., Egypt*, 2008.

[15] A. Negm, G. Abdel-Aal, M. Elfiky, and Y. Mohamed, "Optimal position of curved deflector to minimize scour downstream multi-vents regulators," *Proc. IWTC1,* pp. 27-30, 2008.

[16] G. M. Abdel-Aal, M. R. Fahmy, A. A. Habib, and M. G. Elbagoury, "Scour Downstream Sudden Expansion Stilling Basin.(Dept. C (Irrigation))," *Bulletin of the Faculty of Engineering. Mansoura University,* vol. 40, pp. 39-49, 2020.

[17] A. Uyumaz, "Scour downstream of vertical gate," *Journal of Hydraulic Engineering,* vol. 114, pp. 811-816, 1988.

[18] M. Mohamed and J. McCorquodale, "Short-term local scour," *Journal of Hydraulic Research,* vol. 30, pp. 685-699, 1992.

[19] T. M. Champagne, S. R. Ghimire, B. D. Barkdoll, J. A. González-Castrom, and L. Deaton, "Experiments Identifying Scour-Inducing Flow Patterns at a Gated Weir Stilling Basin," in *Scour and Erosion*, ed, 2010, pp. 678-687.

[20] T. M. Champagne, B. D. Barkdoll, J. A. González-Castro, and L. Deaton, "Experiments identifying worst case scour conditions of gated weir stilling basins," in *World Environmental and Water Resources Congress 2010: Challenges of Change*, 2010, pp. 1905-1914.

[21] M. Shahabi, T. Nasser, D. Ahmad, T. Abdoulrasoul, and R. Reza, "Experimental Investigation of the effect of Contraction on Scouring in Downstream of Combined flow over Weirs and below Gates," in *5 th Symposium on Advances in Science and Technology, Mashhad, Iran, May*, 2011, pp. 12-17.

[22] A. Goel, "Scour Investigations Behind a Vertical Sluice Gate without Apron," *Pacific Journal of Science and Technology,* p. 2, 2010.

[23] A. M. Helmi and M. H. El-Gamal, "Experimental and numerical investigations of flow through free double baffled gates," *Water SA,* vol. 37, 2011.

[24] G. Abdel-Aal, O. Saleh, M. Nassar, and A. Abdel-Ghany, "Examining Free Jump Parameters under the Effect of Two Vertical Overlapping Gates (TVOG)," *Egyptian Journal for Engineering Sciences and Technology,* vol. 22, pp. 1-8, 2017.