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HYDRAULIC ANALYSIS OF COMPOSITE HYDRAULIC STRUCTURE CONSIDERING EXISTING OF PIER

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Abstract: A composite hydraulic structure is used to solve the problems of sediment and floating materials, respectively. A pier (obstacle) is used at the downstream of the composite hydraulic structure to increase water depth, decrease flow velocity, and dissipate the flow energy. The paper deals with the effect of single pier and double piers on the hydraulic characteristics of the composite structure. Circular and square shapes are adopted in the study with different spacing measured from the downstream of the composite structure. The experiments reveal how the level of the hydraulic characteristics is changed due to the existence of the pier/piers as compared to without the existence of the pier/piers. The statistical data which is collected from the experiments shows the alteration in the average downstream water depth, discharge coefficient, Reynolds number, upstream Froude number and downstream Froude number regardless of pier shape and spacing. The alteration happens owing to a change in the separation zone of water flow along the pier circumference. Nonlinear water surface profile is appeared when the pier is located at the downstream, while linear water surface profile is appeared clearly when the downstream without pier. Also the interference between overflow velocity and underflow velocity will be reflected in the hydraulic characteristics.

Keywords: open channel flow, weir, gate, pier

ГИДРАВЛИЧЕСКИЙ АНАЛИЗ СЛОЖНОГО ГИДРОТЕХНИЧЕСКОГО СООРУЖЕНИЯ, ВКЛЮЧАЮЩЕГО ПИРС

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Аннотация: Композиционное гидротехническое сооружение используется для решения проблем, связанных с отложениями и соответственно всплывающими веществами. Пирс (как препятствие) задействован в нижней части сложного гидротехнического сооружения для увеличения глубины воды, уменьшения скорости потока и рассеивания энергии потока. В статье рассмотрено влияние одиночных и двойных свай на гидравлические характеристики составной конструкции. В исследовании приняты круглые и квадратные формы с разным расстоянием, измеренным от нижней части композиционной конструкции. Эксперименты показывают, как изменяется уровень гидравлических характеристик при наличии препятствия/препятствий по сравнению с их отсутствием. Статистические данные, собранные в результате экспериментов, показывают изменение средней глубины воды ниже по течению, коэффициента расхода, числа Рейнольдса, числа Фруда выше по течению и числа Фруда ниже по течению независимо от формы и расстояния между опорами. Изменение происходит за счет изменения зоны отрыва потока воды по окружности пирса. Нелинейный профиль водной поверхности проявляется при расположении пирса в нижнем бьефе, а линейный профиль водной поверхности проявляется четко при нижнем бьефе без пирса. Также на гидравлических характеристиках будет отражаться взаимовлияние скорости перелива и скорости нижнего потока.

Ключевые слова: течение в открытом русле, плотина, затвор, препятствие

INTRODUCTION

The weir and gate composite hydraulic structure is the most common and significant discharge structure in irrigation engineering work. This structure is used for adjusting and controlling the water flow in the channel or canal. The function of using both a weir and a gate in the same structure is to remove the floating material by the weir structure and the sediment by the gate opening at the same time with high efficiency of the operation without any shortages in supply water flow rate. The free flow characteristics of the flow which passes over the weir and under the gate are investigated. The weir has a triangular shape, while the gate has a rectangular shape. Nine different weirs are used with three different angles over a gate with a rectangular section. Also, three different distances between the gate and the weir are considered in the study [1]. The discharge coefficient of a combined hydraulic structure is investigated. Nine different models are used, with the weir having a rectangular shape while the gate has a semi-circular shape. The discharge coefficient of the combined structure is estimated by using a multi-regression model with the percentage of the error equal to ±10% [2]. Also, the flow pattern over the weir and under the gate of the combined weir-gate structure is studied experimentally. In the experiments, four different opening gate heights were adopted. Four different angles for the weir were also adopted in the experiments. Statistical analysis principles are adopted to correlate the discharge coefficient with hydraulic and geometric variables [3]. The discharge coefficient and the free flow characteristics for composite weirs and sluice gates are examined by using experiments. The gate has a semicircular shape with fixed dimensions. Fifteen device models are employed and tested under the action of the different geometrical conditions, while the hydraulic conditions are considered constant. They obtained an expression to describe the device discharge coefficient [4]. As well, the discharge coefficient of the combined weir-gate structure is examined by using experiments under free flow conditions. The weir consists of two parts, and these parts are trapezoidal notch over rectangular notch, while the sluice gate has a semicircular shape. Fifteen device models are employed and tested. From the results of the experiments, they developed and predicted a formula for the discharge coefficient of the device [5]. Experimentally, the hydraulic characteristics of flow over a cipolletti weir and under an opening with a rectangular section are studied. Thirty-nine models are made with different geometrical dimensions. The experiments are done under the free flow condition and subcritical flow [6]. In addition, the characteristics of the combined flow under a rectangular opening and over a trapezoidal weir are studied experimentally. Also, the dimensional analysis with statistics program is employed to obtain an empirical formula to describe the discharge coefficient [7]. The mutual influence of the suspended material and the deposition on the combined hydraulic structure has been studied. Experimental work has been done to validate the composite models. The simulation analysis is based on the RNGK-ε turbulence model. From this study, the prediction of the discharge leads to the suggestion of two mathematical models with an acceptable discharge coefficient [8]. On the other hand, the composite hydraulic structure flow characteristics are studied experimentally under free flow conditions. The study dealt with the influence of the installation angle of the composite structure on the horizontal bed of the flume on hydraulic characteristics, considering different geometrical dimensions of the composite structure [9]. In addition, experimental work is performed to reveal the hydraulic characteristics of water flow that passes through the composite hydraulic structure and encounters obstacles with or without openings, which are located downstream of the composite structure. The experiments show the direct effect of the obstacles with openings on the hydraulic

characteristics and flow pattern [10]. The impact of using the barrier/barriers at the downstream region of the weir-gate structure has been studied experimentally. The experiments reveal the influence of the barrier/barriers on controlling the hydraulic characteristics of the composite hydraulic structure [11]. Also, an experimental study was carried out to show the effect of the downstream obstacle/obstacles on the hydraulic characteristics of the discharge structure (weir-gate structure). The experiments show that the obstacle/obstacles control the trend between the hydraulic variables [12]. The experiment study deals with assessment of the composite structure's hydraulic characteristics under the effect of the pier/piers' existence at the downstream of the composite structure. Here, the pier works as an obstacle and leads to an increased water level around the pier and reduced flow velocity. These factors will be reflected directly on the hydraulic characteristics of the hydraulic structure.

THEORETICAL ANALYSIS

The theoretical discharge, which crosses the rectangular weir, can be computed from the following equation [13].

$$Q_w = \frac{2}{3}\sqrt{2g}\; b\, h^{3/2} \tag{1}$$

The theoretical discharge, which crosses the gate, can be computed from:

$$Q_g = V\,.A = \sqrt{2g\,H}\;A \tag{2}$$

For free flow conditions,

$$H = d + y + h \tag{3}$$

For submerged flow conditions

$$H = d + y + h - h_d \tag{4}$$

For the composite hydraulic structure, which consists of weir and gate, the theoretical discharge and actual discharge can be computed according to:

$$Q_{theor} = Q_w + Q_g \tag{5}$$

$$Q_{act} = C_d \cdot Q_{theor} \tag{6}$$

$$Q_{act} = C_d\,[Q_w + Q_g] \tag{7}$$

Where, H: upstream water depth, h: water head over weir crest, h_d: downstream water depth, y: vertical distance between weir and gate, d: the gate depth, A: gate cross-section flow area, Vis the flow velocity, b: the width of the rectangular weir, g: acceleration due to gravity, Q_w:weir discharge ,Q_g: gate discharge,Q_{theor}: theoretical discharge ,Q_{act}: actual discharge ,C_d: discharge coefficient.

The Reynolds number [14] and Froude number [15] are computed by using the following equations:

$$R_e = \frac{V\,h_d}{\nu} \tag{8}$$

$$F_r = \frac{V}{\sqrt{g\,y}} \tag{9}$$

Where: ν is the kinematic viscosity of water, y: water depth.

EXPERIMENTAL SETUP

The experiments for the current study are done on the flume, which has the following dimensions: 2 m long, 7.5 cm wide, and 15 cm deep. The volume method is used to measure the actual discharge quantity, while the water depth at the upstream and downstream is measured by using a scale mounted on the side wall of the flume. Table 1 displays the dimensions of the test model that is made from wood sheet material; the thickness of wood sheet is equal to 5mm beveled

along all the edges at 45° with sharp edges of 1mm. The composite hydraulic structure is located at a certain distance equal to 80 cm from the beginning of the flume. For all experiments, the bed of the flume must be in a horizontal position. Two different shapes of the pier are used; the first one has a circular shape, while the second one has a square shape.

Table 1. The dimensions of the test models

Model No.	Hu(cm)	D(cm)	Y(cm)	H(cm)
1	3	4	2	9
2	2	4	2	8
3	1	4	2	7
4	3	3	3	9
5	2	3	3	8
6	1	3	3	7
7	2	4	3	9
8	1	4	3	8
9	3	2	4	9
10	2	2	4	8
11	1	2	4	7
12	1	4	4	9

Table 2 reviews the details of the pier. Piers are located at different distances measured from the downstream of the composite hydraulic structure. Also, table 2 illustrates the details of the distances. Here, the pier is made by using wood material. Figure 1-a shows the sketch of the composite structure, while Figure 1-b shows the sketch of the whole hydraulic system, which consists of the composite structure and the pier.

Table 2. Details of the pier with distance measured from the composite hydraulic structure

Circular Pier			
Case	Pier Shape	Diameter	Distance
Single pier	Circular	2cm	20cm
Single pier	Circular	2cm	30cm
Double pier	circular	2cm	20cm,30cm
Single pier	circular	3cm	20cm
Single pier	circular	3cm	30cm
Double pier	circular	3cm	20cm,30cm
Single pier	circular	4cm	20cm
Single pier	circular	4cm	30cm
Double pier	circular	4cm	20cm,30cm
Square Pier			
Case	Pier Shape	Diameter	Distance
Single pier	Square	2cm	20cm
Single pier	Square	2cm	30cm
Double pier	Square	2cm	20cm,30cm
Single pier	Square	3cm	20cm
Single pier	Square	3cm	30cm
Double pier	Square	3cm	20cm,30cm
Single pier	Square	4cm	20cm
Single pier	Square	4cm	30cm
Double pier	Square	4cm	20cm,30cm

RESULTS AND DISCUSSION

A series of experiments were carried out using various dimensions of the composite hydraulic structure with varying pier diameters, shapes, and spacing. Figure 2 shows the discharge coefficient of the composite model variation with the ratio (D/H), where D refers to the circular pier diameter and H refers to the upstream water depth. The figure shows a

comparative study based on two different flow conditions. The first condition refers to the free flow condition, which occurs without the existence of the pier, while the second condition refers to the submerged flow condition, which occurs due to the existence of the pier.

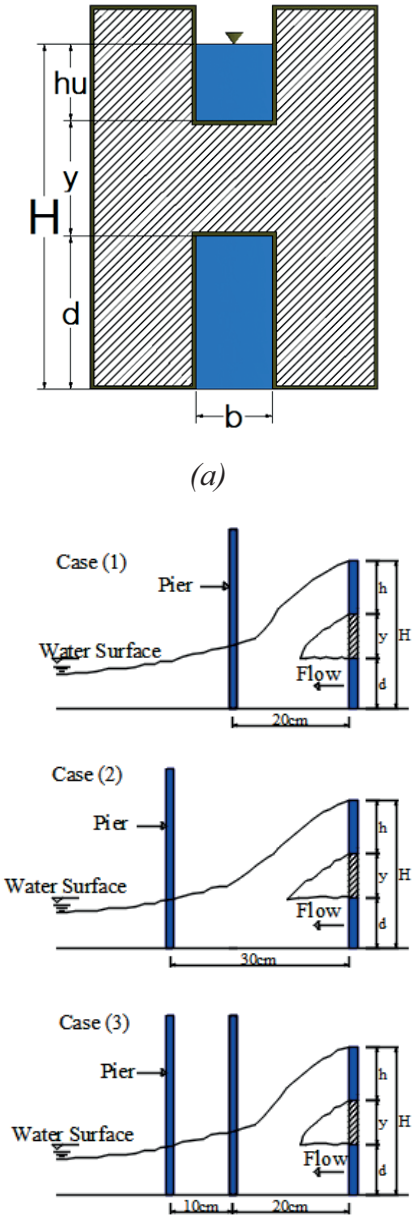


Figure 1. a) The composite structure. b) Composite structure and the Pier

The figure shows that the values of the discharge coefficient in the free flow condition are always greater than the discharge coefficient of the submerged flow condition. The trend in relation between the discharge coefficient and the ratio (D/H) for the submerged flow condition can be considered dramatic owing to the alteration in the pier cross section, spacing, and number of the piers. The variation in the composite discharge coefficient will be associated with the variation in the flow velocity. The variation in the flow velocity happens owing to the alteration in the separation points of the water stream along the circumference of the circular cylinder.

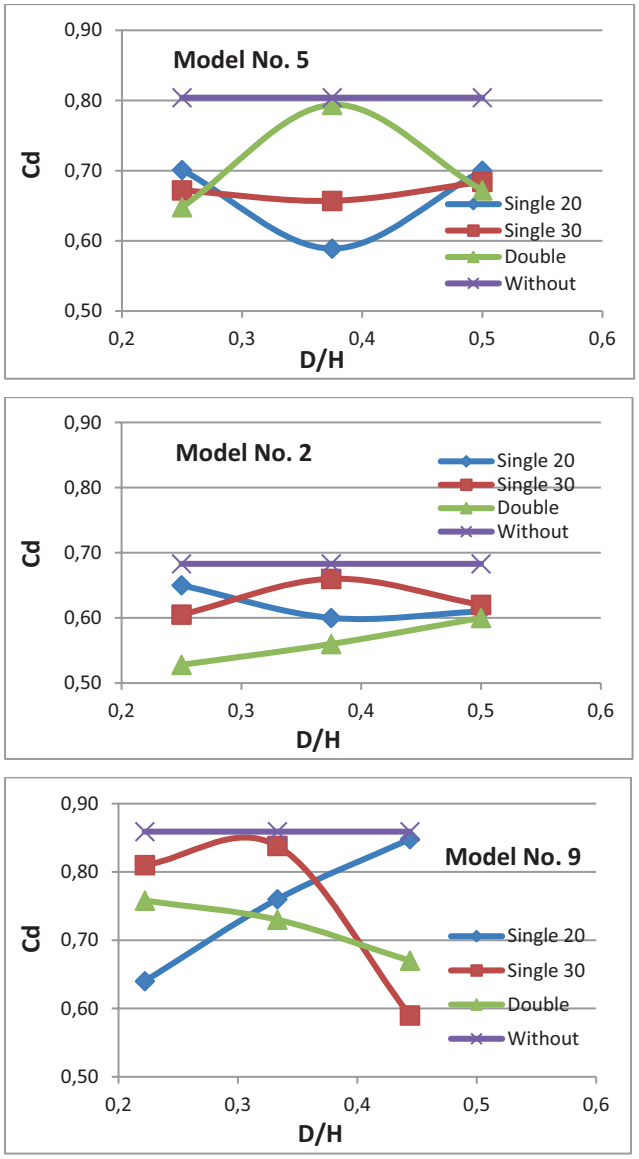


Figure 2. The variation of discharge coefficient with (D/H) ratio of circular pier and for different models

Figure 3 illustrates the variation of the ratio (h_d/H) against the ratio (D/H) for various cases and configurations, where h_d refers to the average downstream water depth. For submerged flow conditions, it is obvious that the ratio (h_d/H) decreases slightly and then increases slightly when the ratio (D/H) increases, while for free flow conditions, by increasing the ratio (D/H), the ratio (h_d/H) remains constant. The figure shows that the values of the submerged flow condition are always greater than the values of the free flow condition. Because of the existence of the pier (obstacle), which confines the water and leads to increasing the water depth, this condition will be satisfied for the submerged flow condition.

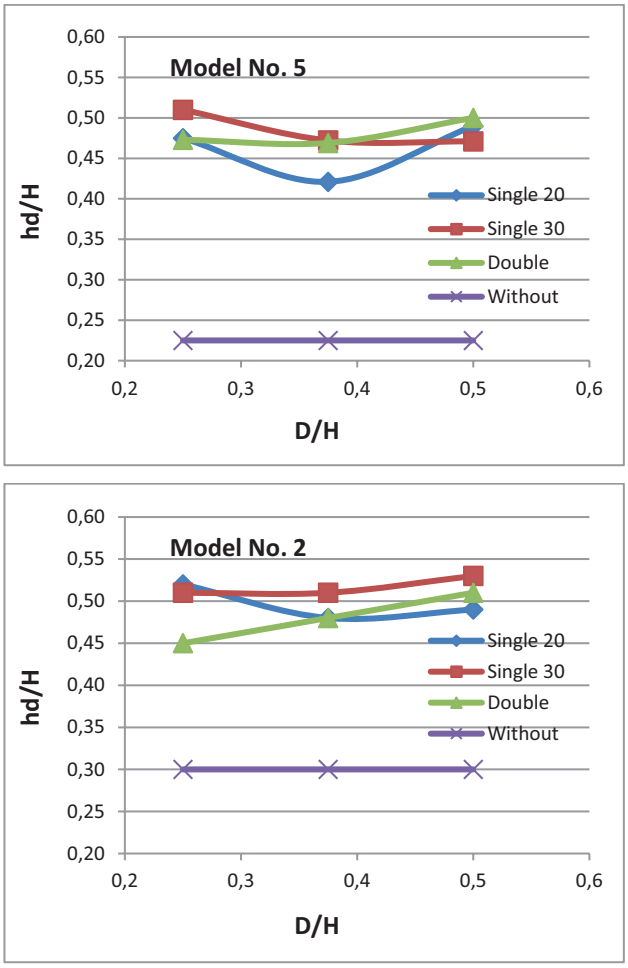


Figure 3. The variation of (h_d/H) ratio with (D/H) ratio of circular pier and for different models

Figure 4 illustrates the relationship between the composite hydraulic structure's actual discharge and the ratio (D/H). The relationship is identical to the trend of the relationship between discharge coefficient and the ratio (D/H), which is shown in figure 2. This happens owing to the direct proportion between actual discharge and discharge coefficient.

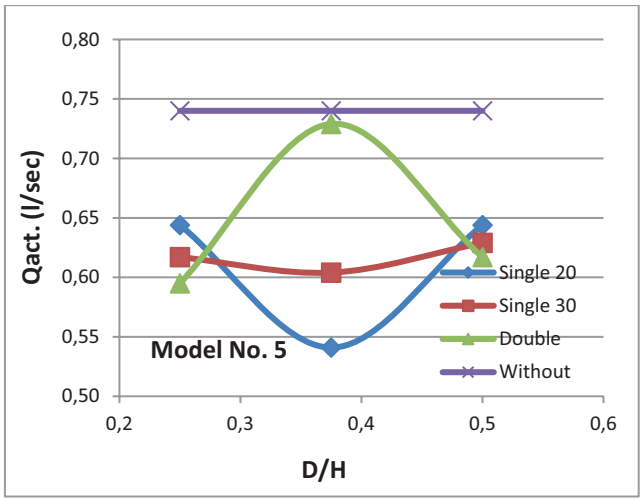


Figure 4. The variation of the actual discahrge with (D/H) ratio of circular pier and for model number 5

Figure 5 illustrates the comparison between free flow and submerged flow for the following relationships: relation between upstream Froude number and the ratio (D/H); downstream Froude number and the ratio (D/H); also the relation between Reynolds number and the ratio (D/H). In general, both the Froude number and the Reynolds number depend on flow velocity and flow depth. The figure shows that the values of the free flow condition are always greater than the values of the submerged flow condition. The justification of this situation is associated with the existence of the pier (obstacle), which leads to the rise in the water depth and decreases Froude number in the downstream region, and this occurs due to the inverse proportion between Froude number and the flow depth. Also, the same behaviour appears

for the Froude number in the upstream region. In the upstream, the flow depth is very high, and this leads to the low values for Froude number. The interaction between weir flow velocity and gate flow velocity has a greater influence on the Reynolds number value distribution than the interaction between flow depth and flow velocity. All three relationships are more influenced by the overlapping between weir velocity and gate velocity, pier diameter, and the spacing between pier and composite structure. Based on the Reynolds number, the flow is considered turbulent. Also, based on the Froude number at upstream, the flow type is considered subcritical and the flow type at downstream is changed from subcritical to supercritical.

Figures 6, 7 and 8 review the relationship between the ratio (h_d/H) and the ratio (X/H), where X refers to the distance along the downstream of the flume, and this distance is measured from the downstream of the composite hydraulic structure. Figures 6 and 7 take into account the existence of single piers and double piers, respectively, while Figure 8 is drawn for both single piers and double piers for a constant ratio of (D/H =0.429). Figures 6, 7 and 8 comprise two different cases. These cases are free flow and submerged flow. The figures show that the values of the average downstream water depth for the free flow are always less than the corresponding values in the case of the submerged flow. The nonlinear water surface profile happens due to the alteration in the water surface elevation around the pier (obstacle), which affects the stability of the water surface elevation along the downstream region. The fluctuation in the trend of the profile relies on pier diameter, spacing, and interference between weir velocity and gate velocity.

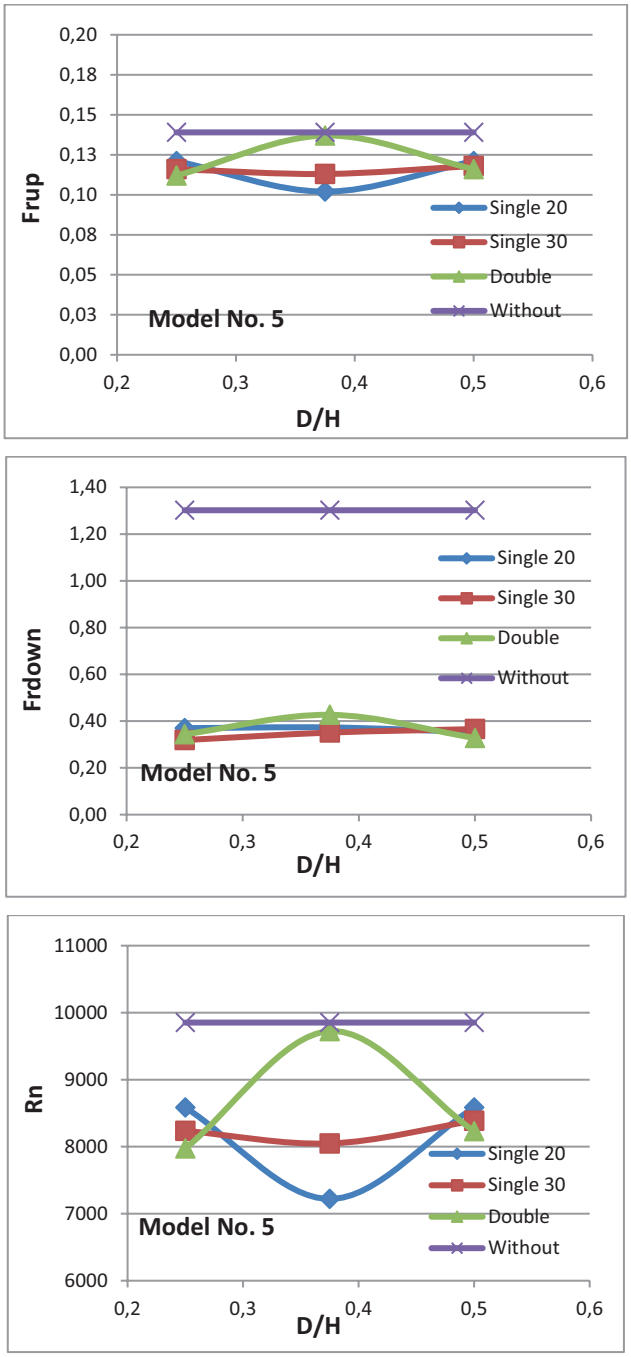


Figure 5. Variation of upstream Froude number, Downstream Froude number and Reynold's number with (D/H) ratio of circular pier and for model No. 5

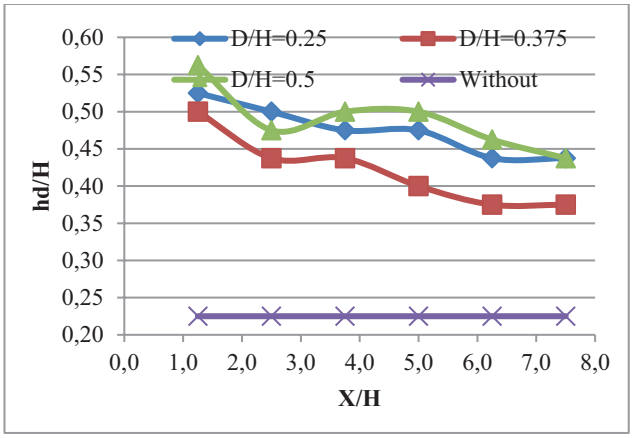


Figure 6. The relationship between (h_d/H) ratio and the ratio (X/H) for model No. 5, Single 20, circular pier

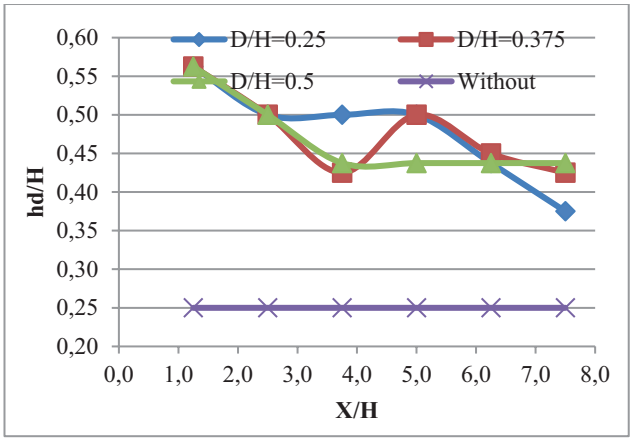


Figure 7. The relationship between (h_d/H) ratio and the ratio (X/H) for model No. 8, double, circular pier

Figure 9 shows the discharge coefficient of the composite model variation with the ratio (D/H), where D refers to the square pier diameter and H refers to the upstream water depth. The figure shows a comparative study based on two different flow conditions. The first condition refers to the free flow condition which occurs without the existence of the pier, while the second condition refers to the submerged flow condition which occurs due to the existence of the pier. The figure shows that the values of the discharge coefficient in the free flow condition are always greater than the discharge coefficient of the submerged flow condition. The trend in relation between the discharge coefficient and the ratio (D/H) for the submerged flow condition can be considered dramatic owing to the alteration in the pier cross section, spacing, and number of the piers. The variation in the composite discharge coefficient will be associated with the variation in the flow velocity. For a single pier, the trend in the relationship is considered identical owing to the separation point of the fluid being considered fixed along the circumference of the square pier. As for the trend, it is starting to increase gradually and drop dramatically. For the double piers, the variation depends on the change in the flow velocity between the front pier and the rear pier.

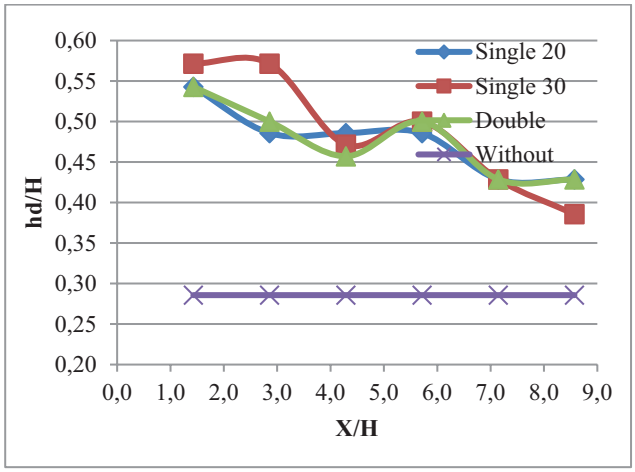


Figure 8. The relationship between (h_d/H) ratio and the ratio (X/H) for model No. 3, D/H=0.429, circular pier

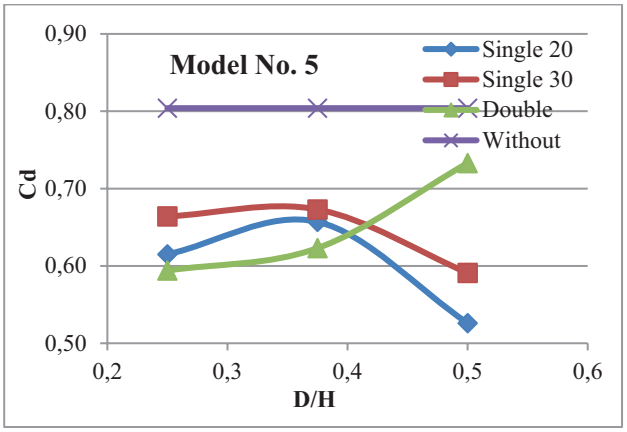


Figure 9. The variation of discharge coefficient with (D/H) ratio of square pier and for model No. 5

Figure 10 illustrates the variation of the ratio (h_d/H) against the ratio (D/H) for various configurations of the pier arrangement, where h_d refers to the average downstream water depth. For submerged flow conditions, it is obvious that the ratio (h_d/H) decreases slightly when the ratio (D/H) increases, while for free flow conditions, by increasing the ratio (D/H), the ratio (h_d/H) remains constant. The figure shows that the values of the submerged flow condition are always greater than the values of the free flow condition. Because of the existence of the pier (obstacle), which confines the water and leads to increasing the water depth, this condition will be satisfied for the submerged flow condition.

Figure 11 illustrates the comparison between free flow and submerged flow for the following relationships: relation between upstream Froude number and the ratio (D/H); downstream Froude number and the ratio (D/H); also the relation between Reynolds number and the ratio (D/H). In general, both the Froude number and the Reynolds number depend on flow velocity and flow depth.

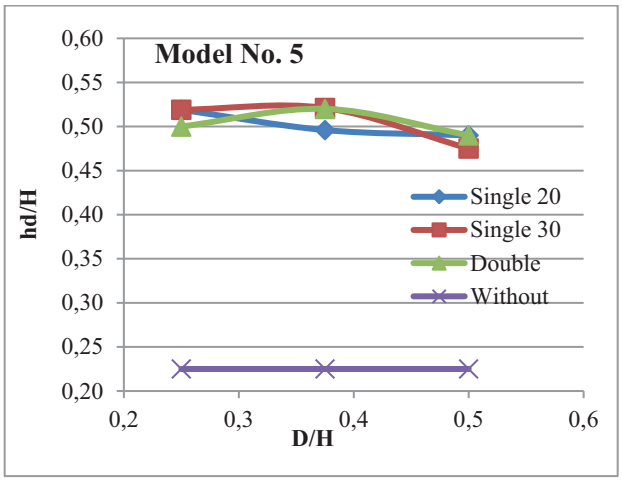
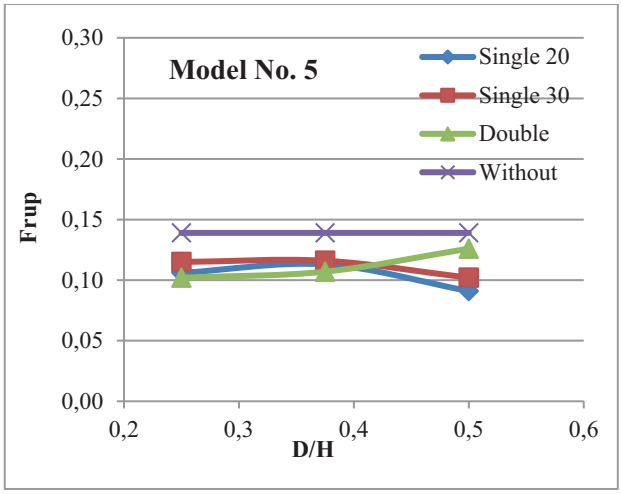
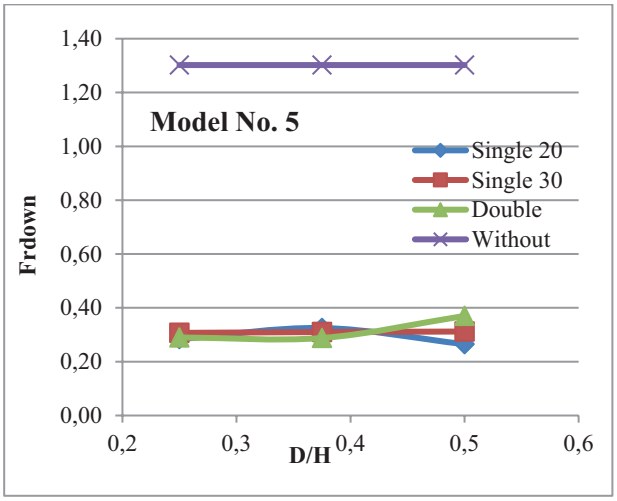


Figure 10. The variation of (h_d/H) ratio with (D/H) ratio of square pier and for model No. 5

The figure shows that the values of the free flow condition are always greater than the values of the submerged flow condition. The justification of this situation is associated with the existence of the pier (obstacle), which leads to the rise in the water depth and decreases Froude number in the downstream region, and this occurs due to the inverse proportion between Froude number and the flow depth. Also, the same behaviour appears for the Froude number in the upstream region. In the upstream, the flow depth is very high, and this leads to the low values for Froude number. The interaction between weir flow velocity and gate flow velocity has a greater influence on the Reynolds number value distribution than the interaction between flow depth and flow velocity. All three relationships are more influenced by the overlapping between weir velocity and gate velocity, pier diameter, and the spacing between pier and composite structure. Based on the Reynolds number, the flow is considered turbulent. Also, based on the Froude number at upstream, the flow type is considered subcritical and the flow type at downstream is changed from subcritical to supercritical.

Figures 12, 13 and 14 review the relationship between the ratio (h_d/H) and the ratio (X/H), where X refers to the distance along the downstream of the flume, and this distance is measured from the downstream of the composite hydraulic structure. Figures 12 and 13 take into account the existence of single piers and double piers, respectively, while Figure 14 is drawn for both single piers and double piers for a constant ratio of (D/H = 0.571). Figures 12, 13 and 14 comprise two different cases. These cases are free flow and submerged flow. The figures show that the values of the average downstream water depth for the free flow are always less than the corresponding values in the case of the submerged flow. The nonlinear water surface profile happens due to the alteration in the water surface elevation around the pier (obstacle), which affects the stability of the water surface elevation along the downstream region. The fluctuation in the trend of the profile relies on pier diameter, spacing, and interference between weir velocity and gate velocity.





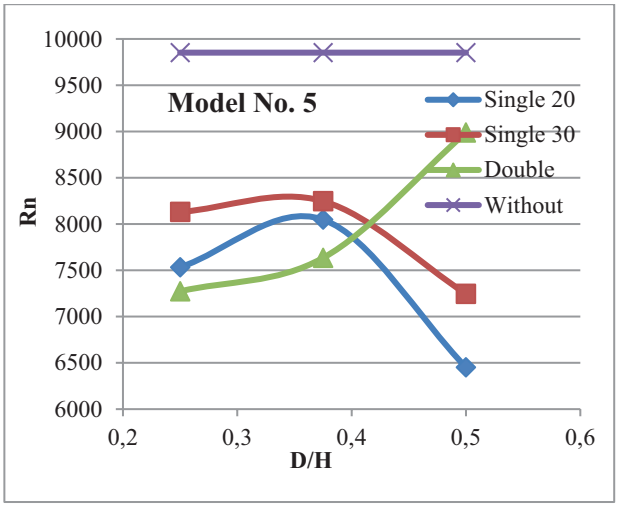


Figure 11. Variation of upstream Froude number, Downstream Froude number and Reynold's number with (D/H) ratio of square pier and for model No. 5

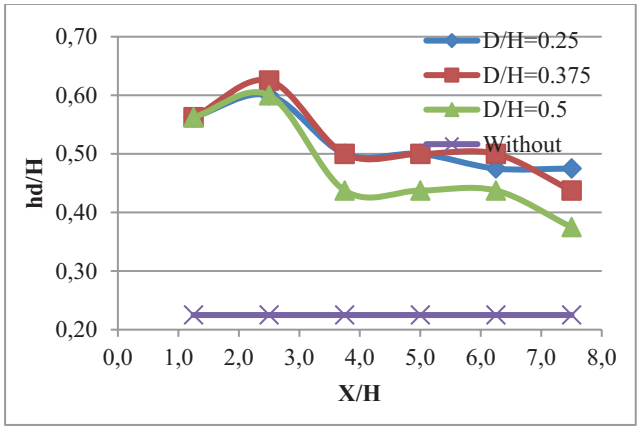


Figure 12. The relationship between (h_d/H) ratio and the ratio (X/H) for model No. 5, Single 30, square pier

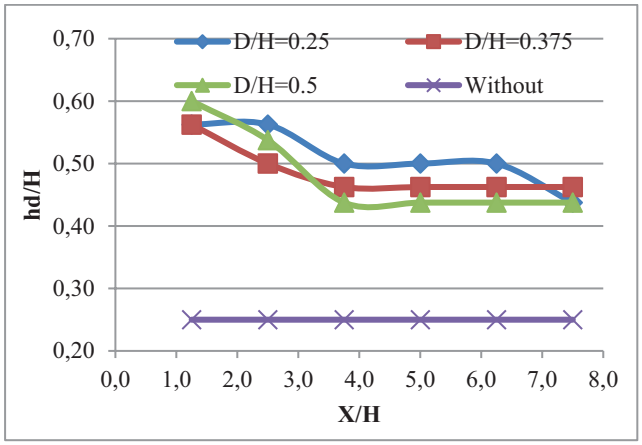


Figure 13. The relationship between (h_d/H) ratio and the ratio (X/H) for model No. 5, double, square pier

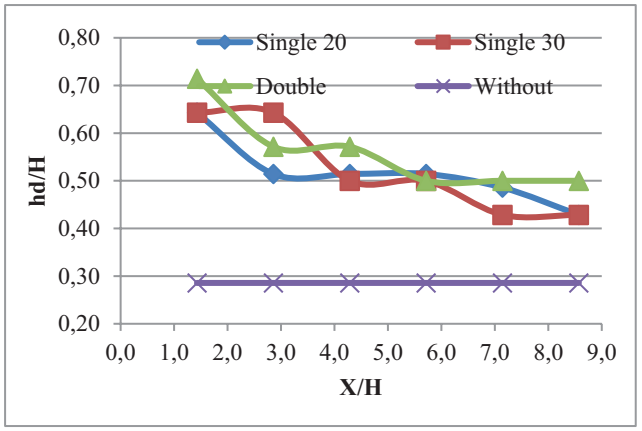


Figure 14. The relationship between (h_d/H) ratio and the ratio (X/H) for model No. 3, D/H=0.571, square pier

Table 3 shows the maximum, minimum, and average values of discharge coefficient; average downstream water depth; upstream Froude number; downstream Froude number; and Reynolds number. Table 3 includes two different shapes of pier. These shapes are the circular pier and the square pier. Also, table 3 reviews the values for single pier and double piers. From table 3, the following is obvious: The existence of a single square pier with a diameter of 20 cm leads to a higher discharge coefficient, with little fluctuation in the average value. But in the case of double piers, the existence of the double circular piers leads to a higher discharge coefficient as compared with the existence of the double square piers. Also, for a single circular pier with a 30 cm diameter and a single square pier with a 30 cm diameter, the variation in discharge coefficient values appears clearly. For the average downstream water depth, the existence of the square pier leads to higher water depth as compared with the existence of the circular pier regardless of the pier numbers (single or double). A small difference appeared in values of the Froude number upstream regardless of the pier shapes and numbers (single or double). The Froude number downstream has a higher value with a single circular pier with a diameter of 20 cm. Also, Froude number has higher values with double circular piers, but for a single square pier with a diameter of 30 cm, Froude number has higher values as compared with a single square pier with a 20 cm diameter and double square piers. In terms of Reynolds number, the variation in values is obvious regardless of pier shape and configuration (single or double). Variation in all values will be produced by the change in fluid separation zone; flow velocity change from section to section; water depth alteration from section to section; and the change in momentum transfer due to the existence of the pier (obstacle). Also, the table indicates a comparative between two cases; the first case deals with pier existence while the second is without pier existence.

Table 3. Comparison between ferr and submerged output models parameters

Parameter		Circular			Square			Case without
		Single 20cm	Single 30cm	Double	Single 20cm	Single 30cm	Double	
Cd	Maximum	0.892	0.892	0.926	0.897	0.838	0.781	0.859
	Minimum	0.444	0.020	0.502	0.496	0.426	0.434	0.586
	Average	0.630	0.630	0.641	0.602	0.593	0.601	0.750
h_{davg} (cm)	Maximum	4.500	4.683	4.400	4.617	4.617	4.633	3.500
	Minimum	2.783	2.967	3.067	3.167	3.283	3.333	0.850
	Average	3.758	3.925	3.823	4.037	4.082	4.087	1.854
Fr_{up}	Maximum	0.143	0.146	0.147	0.143	0.130	0.153	0.178
	Minimum	0.066	0.003	0.073	0.064	0.068	0.082	0.094
	Average	0.110	0.111	0.111	0.105	0.103	0.106	0.132
Fr_{down}	Maximum	0.470	0.413	0.427	0.397	0.358	0.370	3.919
	Minimum	0.250	0.009	0.262	0.193	0.166	0.222	0.522
	Average	0.352	0.332	0.351	0.303	0.290	0.300	1.483
Rn	Maximum	10695	11257	11407	10959	9852	10870	10999
	Minimum	3810	182	5289	3711	3953	4779	5467
	Average	8125	8194	8313	7795	7571	7830	9597

CONCLUSION

In the current study, flow over weir and under gates with and without single pier or double piers has been studied experimentally. Depending on the experimental results of the current investigation, the following conclusions can be found:

1- The water flow separation zone along the circumference of the pier has a major effect on the hydraulic characteristics, especially the flow velocity.
2- The interaction between gate flow velocity and weir flow velocity produces a variation in the hydraulic characteristics of the composite structure.
3- The pier shape and spacing have a direct effect on the control of the hydraulic behavior of the composite hydraulic structure.
4- The change in water depth, flow velocity, and momentum transfer will have an effect directly on the hydraulic characteristics of the composite structure.
5- Actual discharge and discharge coefficient have the same trend regardless of the presence of the pier/piers.
6- The Reynolds number and Froude number are more sensitive to the existence of the pier/piers.
7- The hydraulic characteristics of the composite structure under the action of the pier/piers are not similar to the hydraulic characteristics without the pier/piers.

REFERENCES

1. **Hayawi, H.A.M., Yahia, A.A.G., Hayawi, G.A.M.** Free combined flow over a triangular weir and under rectangular gate. Damascus Univ. Journal. 2008. 24 (1).
2. **Hayawi, H.A.M., Hayawi, G.A.M., Alniami, A.A.G.** Coefficient of discharge for a combined hydraulic measuring device. Al-Rafidain Engineering. 2009. 17(6). http://dx.doi.org/10.33899/rengj.2009.43616.
3. **Jalil, A.S., Sarhan, A.S.** Experimental study of combined oblique weir and gate structure. ARPN Journal of Engineering and Applied Sciences. 2013. 8(4).
4. **Khassaf, S.I., Yost, S.A., Abbas, H.A.** Coefficient of discharge for a compound weir with semicircular gate. International Journal of Advance Research. IJOAR.org. 2013. 1(Issue 9).
5. **Khassaf, S.I., Abbas, H.A.** Study the free flow over compound weir and below semi circular gate. International Journal of Scientific & Engineering Research. 2013. 4(Issue 10).
6. **Al-Suhili, R.H., Shwana, A.J.** Prediction of the discharge coefficient for a cipolletti weir with rectangular bottom opening. Int. Journal of Engineering Research and Applications. 2014. 4(Issue 1). (Version 4), 80-89.
7. **Khassaf, S.I., Habeeb, M.** Experimental investigation for flow through combined trapezoidal weir and rectangular gate. International Journal of Scientific & Engineering Research. 2014. 5(Issue 4).
8. **Sarhan, S.A., Jalil, S.A.** Analysis of simulation outputs for the mutual effect of flow in weir and gate system. Journal of Babylon University/Engineering Sciences. 2018. 26(6).
9. **Qasim, R.M., Abdulhussein, I.A., AL-Asadi, K.** Experimental study of composite inclined weir – gate hydraulic structure. WSEAS TRANSACTIONS on FLUID MECHANICS, 2020. 15. DOI: 10.37394/232013.2020.15.5
10. **Qasim, R.M., Abdulhussein, I.A., Mohammed, A.A., Maatooq, Q.A.** The effect of the obstacle on the hydraulic response of the composite hydraulic structure. INCAS BULLETIN. 2020. 12(Issue 3). 159 – 172. DOI: 10.13111/2066-8201.2020.12.3.13
11. **Qasim, R.M. Abdulhussein, I.A., AL-Asadi, K.** The effect of barrier on the hydraulic response of composite weir-gate structure. Archives of Civil Engineering.

2020. 66 (Issue 4). DOI: 10.24425/ace.2020.135211
12. **Qasim, R.M., Mohammed, A.A., Abdulhussein, I.A., Maatooq, Q.A.** Experimental invistigation of multi obsticales impact on weir-gate discharge structure. International Journal of Mechatronics and Applied Mechanics. 2021. Issue 9. dx.doi.org/10.17683/ijomam/issue9.11
13. **Streeter, V.L., Wylie, E.B.** Fluid mechanics, First SI Metric Edition, Copy right©. 1983.
14. **Negm, A.M., AL- Brahim, M., ALHamid, A.A.** Combined-free flow over weirs and below gates. J. Hydraul. Res. 2002. 40. 1–7.
15. **Fox, R.W., McDonald, A.T.** Introduction to fluid mechanics. Fourth Edition. SI version Copyright © John Wiley and Sons, Inc. 1994.

СПИСОК ЛИТЕРАТУРЫ

1. **Hayawi, H.A.M., Yahia, A.A.G., Hayawi, G.A.M.** Free combined flow over a triangular weir and under rectangular gate. Damascus Univ. Journal. 2008. 24 (1).
2. **Hayawi, H.A.M., Hayawi, G.A.M., Alniami, A.A.G.** Coefficient of discharge for a combined hydraulic measuring device. Al-Rafidain Engineering. 2009. 17(6). http://dx.doi.org/10.33899/rengj.2009.43616.
3. **Jalil, A.S., Sarhan, A.S.** Experimental study of combined oblique weir and gate structure. ARPN Journal of Engineering and Applied Sciences. 2013. 8(4).
4. **Khassaf, S.I., Yost, S.A., Abbas, H.A.** Coefficient of discharge for a compound weir with semicircular gate. International Journal of Advance Research. IJOAR.org. 2013. 1 (Issue 9).
5. **Khassaf, S.I., Abbas, H.A.** Study the free flow over compound weir and below semi circular gate. International Journal of Scientific & Engineering Research. 2013. 4 (Issue 10).
6. **Al-Suhili, R.H., Shwana, A.J.** Prediction of the discharge coefficient for a cipolletti weir with rectangular bottom opening. Int. Journal of Engineering Research and Applications. 2014. 4 (Issue 1). (Version 4), 80-89.
7. **Khassaf, S.I., Habeeb, M.** Experimental investigation for flow through combined trapezoidal weir and rectangular gate. International Journal of Scientific & Engineering Research. 2014. 5(Issue 4).
8. **Sarhan, S.A., Jalil, S.A.** Analysis of simulation outputs for the mutual effect of flow in weir and gate system. Journal of Babylon University/Engineering Sciences. 2018. 26(6).
9. **Qasim, R.M. Abdulhussein, I.A., AL-Asadi, K.** Experimental study of composite inclined weir – gate hydraulic structure. WSEAS TRANSACTIONS on FLUID MECHANICS, 2020. 15.DOI: 10.37394/232013.2020.15.5
10. **Qasim, R.M. Abdulhussein, I.A., Mohammed, A.A., Maatooq, Q.A.** The effect of the obstacle on the hydraulic response of the composite hydraulic structure. INCAS BULLETIN. 2020. 12 (Issue 3). 159 – 172. DOI: 10.13111/2066-8201.2020.12.3.13
11. **Qasim, R.M. Abdulhussein, I.A., AL-Asadi, K.** The effect of barrier on the hydraulic response of composite weir-gate structure. Archives of Civil Engineering. 2020. 66 (Issue 4). DOI: 10.24425/ace.2020.135211
12. **Qasim, R.M., Mohammed, A.A., Abdulhussein, I.A., Maatooq, Q.A.** Experimental invistigation of multi obsticales impact on weir-gate discharge structure. International Journal of Mechatronics and Applied Mechanics. 2021. Issue 9. dx.doi.org/10.17683/ijomam/issue9.11
13. **Streeter, V.L., Wylie, E.B.** Fluid mechanics, First SI Metric Edition, Copy right©. 1983.

14. **Negm, A.M., AL- Brahim, M., ALHamid, A.A.** Combined-free flow over weirs and below gates. J. Hydraul. Res. 2002. 40. 1–7.

15. **Fox, R.W., McDonald, A.T.** Introduction to fluid mechanics. Fourth Edition. SI version Copyright © John Wiley and Sons, Inc. 1994.

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