[1.]R.M. QASIM, [2.]I.A. ABDULHUSSEIN, [3.]M.A. HAMEED, [4.]Q.A. MAATOOQ

EXPERIMENTAL STUDY OF HYDRAULIC RESPONSE FOR COMBINED WEIR-GATE FLOW OF COMPOSITE SHAPE

[1,2,4.] Basrah Engineering Technical College, Southern Technical University, IRAQ
[3] Technical Institute of Basrah, Southern Technical University, IRAQ

Abstract: Composite hydraulic structures play a vital role in controlling the flow in the irrigation system because of the interaction between over flow velocity from weir and under flow velocity from gate and this interaction will reflect on hydraulic response of structure. In the present work, numerous experiments were carried out in the laboratory of hydraulic engineering considering many variables that have direct contact in flow interaction and these variables are divided into two parts: the first is non-dimensional variable such as coefficient of discharge, Reynolds number and Froude number. The second is dimensional variable flow-rate and water depth above weir. These variables are considered for both upstream and downstream of the flume respectively and for different tested models of composite device. This study reviews that the flow velocity and the flow depth of water above the weir have major effect on hydraulic response in upstream and downstream of the flume respectively. The hydraulic response express in term of non-dimensional variable and dimensional variable.
Keywords: Composite hydraulic structure, Composite device, Froude number, Reynolds number

1. INTRODUCTION

Weirs and gates are the common and important structures which are used in controlling and adjusting the flow in irrigation channel. Weirs are widely used for flow measurements, whereas gates are used for flow control and water measurement. The disadvantage of the gates is they retained the floating materials while the disadvantage of weirs is that they retained the sediment particle. In order to overcome this problem, weirs and gates can be combined together in one device, so that water could pass over the weir and through the gate simultaneously. This compound device create a new hydraulically condition in compression with weir or gate, each other alone. The combined weir and gate systems can be used in minimizing sedimentations and depositions. Several works can be found in combined overflow and underflow that the first idea of simultaneous flow over the weir and under the gate was introduced by Majcherek (1984). Negm (1995, 1996) analyzed the characteristics of the combined flow over contracted weirs and below contracted gates of rectangular shape with unequal contractions. Alhamid (1999) studied combined flow over V-notch weir and below contracted rectangular gate. This study covered both free and submerged gate flow conditions, under different weir-gate dimensions. Based on dimensional analysis and using non-linear regression analysis, discharge equation was developed for both free and submerged gate flows. Negm et al. (2002) conducted some experiments to study the characteristics of the combined flow over the sharp-edged rectangular weir and below the sharp-edged rectangular gate with contractions. He introduced a general dimensionless relationship for predicting the discharge of the combined flow. Recently, many researchers have carried out experiments to investigate the hydraulic characteristics of combined weir-gate flow using different composite shapes like (Al-Saadi, 2013), (Khassaf and Habeeb, 2014), (Obead and Hamad, 2014), and (Hassan et.al., 2015).

In the present work, an experimental study on the hydraulic response of combined over flow weirs and under flow gate is investigated. The composite shapes considered were (v-notch combined weir with a triangular gate, rectangular combined weir with a rectangular gate, and trapezoidal combined weir with a trapezoidal gate).

2. BASIC OF FLUID MECHANICS

The present work deals with three different type of composite hydraulic structure or device (weir-gate) these are:

— Triangular weir (V-notch) – Triangular gate

To estimate the flow-rate through combined device for the free flow case, the flow-rate represents the incorporation of both gate and weir

$$Q_{theor} = Q_w + Q_g \tag{1}$$

To calculate the flow – rate through weir (V-notch) (Streeter, 1989)

$$Q_{weir} = \frac{8}{15}\sqrt{2g}\ \tan\frac{\emptyset}{2}\ h^{5/2} \tag{2}$$

To estimate the flow-rate through gate, from continuity equation (Streeter, 1989)

$$Q = V\,A \tag{3}$$

$$Q_{gate} = V\,A = \sqrt{2gH}\,A \tag{4}$$

For free flow

$$H = d + y + h \tag{5}$$

$$Q_{act} = c_d \, Q_{theor} \tag{6}$$

$$Q_{act} = c_d \left[\frac{8}{15}\sqrt{2g}\ \tan\frac{\emptyset}{2}\ \ h^{5/2} + \sqrt{2gH}\,A\right] \tag{7}$$

— Rectangular weir – Rectangular gates

To estimate the flow-rate through combined device for the free flow case, the flow-rate represents the incorporation of both gate and weir

$$Q_{theor} = Q_w + Q_g \tag{8}$$

To calculate the flow – rate through weir (Streeter, 1983)

$$Q_{weir} = \frac{2}{3}\sqrt{2g}\ b\,h^{3/2} \tag{9}$$

To estimate the flow-rate through gate, from continuity equation (Streeter, 1989)

$$Q = V\,A \tag{10}$$

$$Q_{gate} = V\,A = \sqrt{2gH}\,A \tag{11}$$

For free flow

$$H = d + y + h \tag{12}$$

$$Q_{act} = c_d \, Q_{theor} \tag{13}$$

$$Q_{act} = c_d \left[\frac{2}{3}\sqrt{2g}\ b\,h^{3/2} + \sqrt{2gH}\,A\right] \tag{14}$$

— Trapezoidal weir – Trapezoidal gates

To estimate the flow-rate through combined device for the free flow case, the flow-rate represents the incorporation of both gate and weir

$$Q_{theor} = Q_w + Q_g \tag{15}$$

$$Q_{weir} = Q_{V-notch} + Q_{Rectangulr} \tag{16}$$

$$Q_{weir} = \frac{8}{15}\sqrt{2g}\ \tan\frac{\emptyset}{2}\ \ h^{5/2} + \frac{2}{3}\sqrt{2g}\ b\,h^{3/2} \tag{17}$$

$$Q_{gate} = Q_{triangulat} + Q_{rectangular} \tag{18}$$

$$Q_{gate} = V\,A_{triangular} + V\,A_{rectangular} \tag{19}$$

$$Q_{gate} = V\left(A_{triangular} + A_{rectangular}\right) \tag{20}$$

$$V = \sqrt{2gH} \tag{21}$$

For free flow

$$H = d + y + h \tag{22}$$

$$Q_{act} = c_d \, Q_{theor} \tag{23}$$

$$Q_{act} = c_d \left[\left(\frac{8}{15}\sqrt{2g}\ \tan\frac{\emptyset}{2}\ \ h^{5/2} + \frac{2}{3}\sqrt{2g}\ b\,h^{3/2}\right) + V\left(A_{triangular} + A_{rectangular}\right)\right] \tag{24}$$

where: H: Upstream water depth of the gate, h: Water head above sharp crest weir, y: Vertical distance between weir and gate, d: Water depth of gate opening, A: Cross sectional area of flow, b: Width of rectangular weir, V: Flow velocity through gate, Q_{teor}: theoretical discharge, Q_{act}: actual discharge, c_d: coefficient of discharge

To calculate the Froude Number (Fox and McDonald, 1994):

$$F_r = \frac{V}{\sqrt{gy}} \tag{25}$$

where, V: water flow velocity, g: acceleration of gravity and y: water depth.

3. EXPERIMENTAL STUDY

The experiments were carried out in a rectangular glass sided flume with a dimension of 200cm length, 15cm depth and 7.5 cm width. The discharge is measured using the volume method while the average water depth is measured by the scales fixed in the wall of the flume. Figure 1 shows the combinations shapes which considered in the present work. Table 1 reviews selected dimensions of the triangular, rectangular, and trapezoidal models that fabricate from wood material. Table 2 reviews selected information that was obtained from experimental study performed in laboratory. The following procedures are adopted in laboratory test (Qasim et. al., 2018).

- The slope of the flume is always in horizontal position.
- The models were fixed into flume at distance 80cm from the beginning of the flume.
- The free flow condition is satisfied by removing the tail gate from the channel.

The above procedure was repeated for all models. Sixty models were tested (18 of triangle shape, 24 rectangle shape, and 18 trapezoidal shape) involving the following limitations: $2 \le y \le 6$, $2 \le d \le 4$, $2 \le b \le 3.484$, $1.0722 \le b1 \le 2.8$, $1 \le h_u \le 3$. Models are made of wood sheet 5mm thick beveled along all the edges at 45^0 with sharp edges of thickness 1mm (Qasim et. al., 2018). Models are fixed to flume using plexiglass supports. The selection of the flume and model material was based on the available laboratory facilities. In each test, combined flow rate, Q_{act}, head over the weir, h_u, downstream flow depth, h_d, and upstream flow depth, H, are measured under free flow conditions. The triangular, rectangular, and trapezoidal shapes were adopted in the present study.

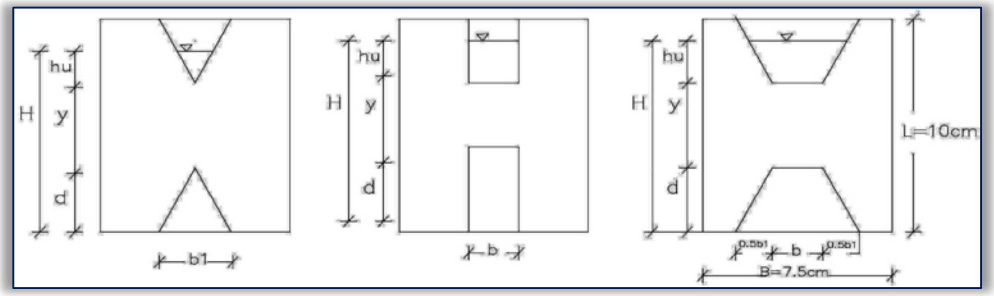

Figure 1. Definition Sketch for the Three Models of Combined Free Flow over Weir and under Gate

Table 1. The Tested Model Dimensions and Details of Selected Different Shapes of weir and Gate

Model	Model No.	h_u (cm)	y (cm)	d (cm)	b (cm)	b1 (cm)	H (cm)
V-notch Combined Weir with a Triangular Gate	1--2—1	1	5	3	2.8	1.072	9
	1--5—2	2	4	2	2.0	2.00	8
	1--8—3	3	3	3	2.8	2.80	9
Rectangular combined weir with a rectangular gate	2--2—1	1	4	2	2.0	--	7
	2--6—2	2	3	3	2.0	--	8
	2--9—3	3	2	4	2.0	--	9
Trapezoidal combined weir with a trapezoidal gate	3--3—1	1	5	2	2.0	--	8
	3--6—2	2	4	3	2.0	--	9
	3--9—3	3	2	4	2.0	--	9

Table 2. Results of the Selected Experimental Models

Model No.	h_d (cm)	Fr_{down}	Fr_{up}	R_N	y/H	$Q_{act.}$ (l/sec.)	Q_{theo} (l/sec.)	Cd
1--2—1	0.80	2.804	0.074	6286	0.5556	0.4715	0.650	0.725
1--5—2	1.60	0.917	0.082	5814	0.5000	0.4360	0.771	0.565
1--8—3	2.00	1.172	0.122	10390	0.3333	0.7792	1.993	0.3910
2--2—1	0.85	2.227	0.094	5467	0.5714	0.4100	0.528	0.777
2--6—2	1.80	1.302	0.139	9852	0.3750	0.7389	0.919	0.804
2--9—3	3.50	0.522	0.126	10705	0.2222	0.8029	1.370	0.586
3--3—1	1.90	1.239	0.143	10169	0.6250	0.763	0.833	0.916
3--6—2	2.50	1.106	0.162	13698	0.4444	1.027	1.635	0.628
3--9—3	4.00	0.556	0.165	13937	0.2222	1.045	2.592	0.403

4. RESULT AND DISCUSSION

It is very important to study the effect of hydraulic structure and structure of water control on hydraulic properties of flow and the relationship between the hydraulic properties and flume or artificial channel due to construction of hydraulic structure these factors reflect on hydraulic response of device.

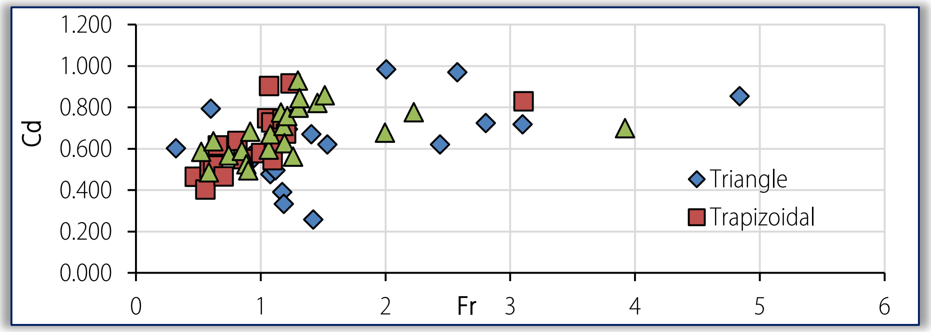

Figure 2. Variation of Coefficient of discharge with downstream Froude Number

Figure 2 reviews the relation between discharge coefficient and Froude number for downstream region. It is clear from this figure that the value of discharge coefficient distributed unequal around $\mathrm{F_r} = 1$. This means that when Froude number less than unity the gravity force is more dominate and the value of discharge coefficient influencing by gravity force. Also, when the gravity force is dominated the flow velocity is considered low and this will reflected on the calculated value of discharge coefficient. When the Froude number greater than unity this means that the inertial force is dominated and the value of discharge coefficient will influencing by inertial force. Also, when the inertial force is dominated the flow velocity is considered high and this will effect on calculated value of discharge coefficient. Due to the change in the value of water depth at weir and gate this will reflect on the variation in estimated value between Froude number and coefficient of discharge. Figure 3 shows the relationship between Reynolds number and Froude number. The both non-dimensional numbers depend on water depth, but Reynolds number proportional direct with water depth while Froude number inversely proportional, so the infer as Froude number increases Reynolds number decreases and vice versa. Figure 4 shows that as Froude number increases the discharge will decrease because of the discharge having direct proportional with flow velocity which depends on flow depth and Froude number have inversely proportional with flow depth and the flow depth have major effect on both discharge and Froude number. It is observed that V-notch weir combined with triangular gate has recorded highest value of both downstream Froud number, Fr_{down}=4.838, and coefficient of discharge, C_d=0.984.

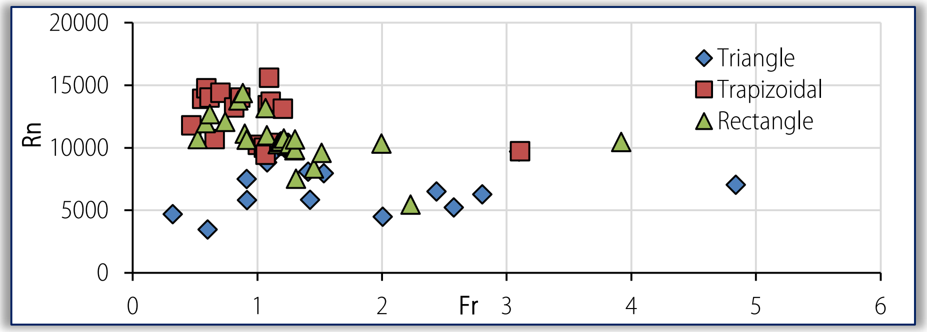

Figure 3. Variation of Reynolds Number with downstream Froud Number

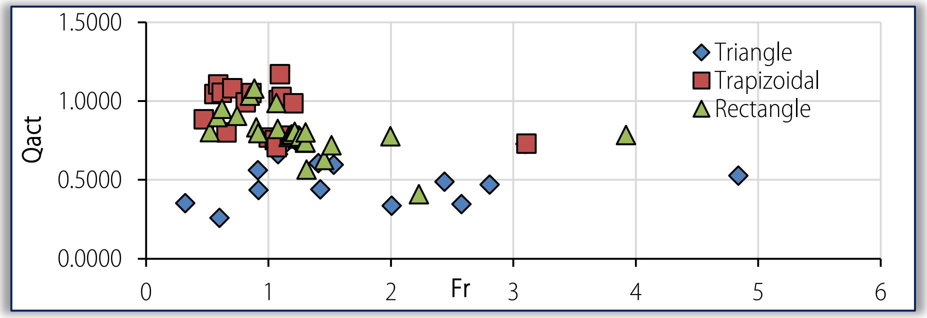

Figure 4. Variation of Measured Discharge with downstream Froud Number

Figure 5 is showing the relationship between discharge coefficient and Froude number for upstream. All values of Froude number less than unity means that the gravity force is dominated and this lead to low flow velocity. The flow velocity has direct proportional with Froude number and inversely proportional with discharge coefficient. So, as Froude number increases the discharge coefficient decreases and vice versa. Figure 6 shows both non-dimensional number depend on flow velocity and water depth. The water depth in upstream of flume is considered constant, so we infer water depth have minor influence. Also, both non-dimensional numbers have direct proportional with velocity, this leads to increase in any non-dimensional value. Therefore, as Froude number increases the Reynolds number must be increases in upstream of flume flow. Figure 7 shows both Froude number and discharge increases in upstream flow of flume because of both discharge and Froude number have direct proportional with flow velocity, so the increase in flow velocity will reflect on both, take in consideration the water depth at upstream of the flume is considered constant. So, the increase in discharge leads to increase in Froude number. It is observed that rectangular weir combined with rectangular gate has recorded highest value of upstream Froud number, Fr_{up}=0.219. Also, it is clear that trapezoidal weir combined with trapezoidal gate has recorded highest value of both Reynold's number, R_N=15625, and actual discharge, $Q_{act.}$=1.172 l/sec.

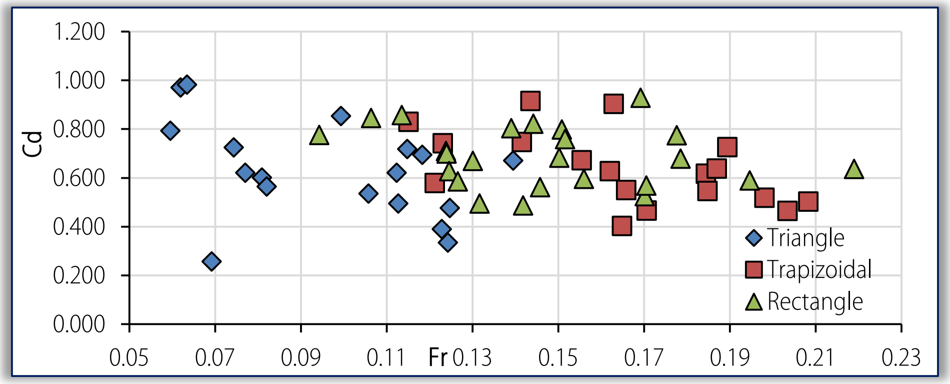

Figure 5. Variation of Coefficient of discharge with Upstream Froud Number

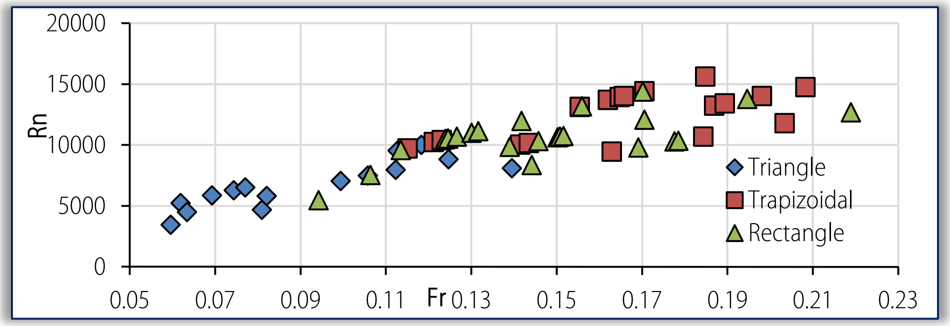

Figure 6. Variation of Reynolds Number with Upstream Froud Number

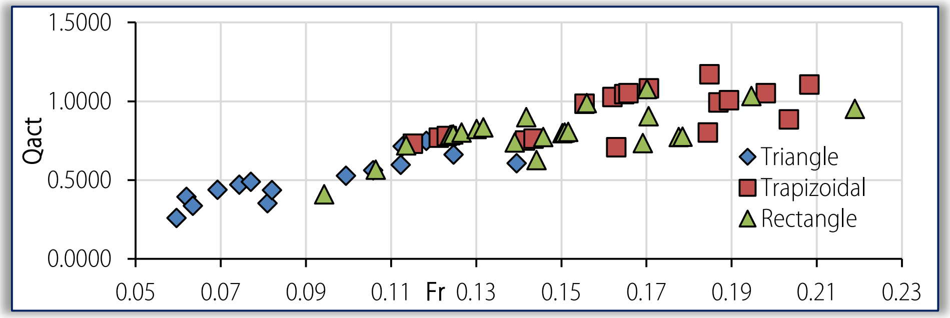

Figure 7. Variation of Measured Discharge with Upstream Froud Number

Figure 8 reviews the relationship between discharge coefficient and water depth above sharp crest. It is obvious from this figure that, as the water depth increases the discharge coefficient decreases due to inversely proportional between water depth above weir and discharge coefficient. Sometime variation occurs due to overlapping in velocity of weir and gate. Figure 9 reviews the relationship between discharge and water depth above weir. Actually, as the water depth above weir increases the discharge must be increased because the direct proportional between flow velocity and water depth and from continuity equation the discharge depends on flow velocity. Also, the variation in value of discharge with water depth above weir occurs due to overlapping between flow over weir and flow under gate. It is evident from Figures 10 and 11 as water depth above weir increases the Froude number decreases due to inversely proportional between Froude number and water depth. It is clear from Figure 12 as water depth above weir increases the Reynolds number must be increases due to direct proportional between Reynolds number and water depth above weir. The contrast in some point in the relation actually depends on flow interaction between weir and gate.

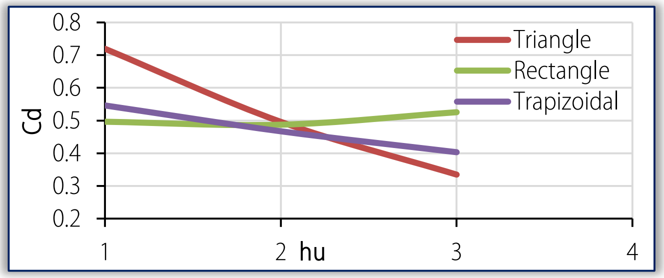

Figure 8. Variation of Discharge Coefficient with depth above weir for H=9cm, d=4cm

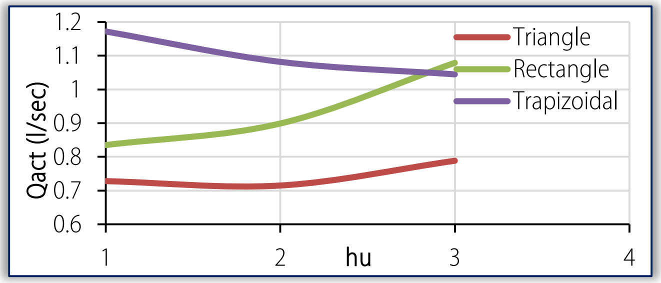

Figure 9. Variation of Measured Discharge with depth above weir for H=9cm, d=4cm

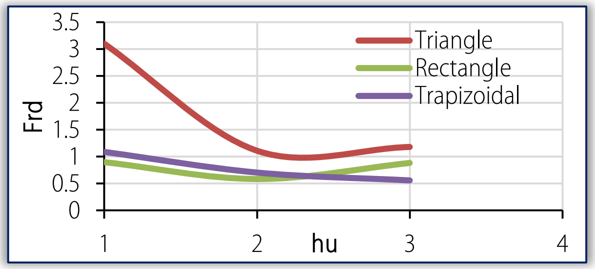

Figure 10. Variation of Downstream Froud Number with depth above weir for H=9cm, d=4cm

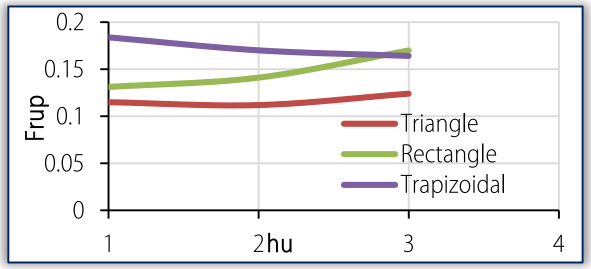

Figure 11. Variation of upstream Froud Number with depth above weir for H=9cm, d=4cm

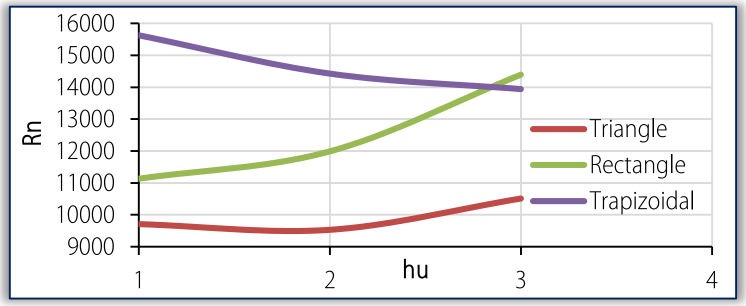

Figure 12. Variation of Reynolds Number with depth above weir for H=9cm, d=4cm

5. CONCLUSIONS

- The limit of Froude number in upstream of flume does not match the Froude number in downstream.
- Froude number represents a good parameter to determine velocity level from high to low or from low to high.
- Froude number has major effect on discharge coefficient in the region before hydraulic device and in the region after hydraulic device.
- The relationship between Reynolds number and Froude number in upstream dose not identical with same relation in downstream.
- The relationship between flow-rate and Froude number in upstream is identical with same relation in downstream.
- The values of water depth at weir have major effect on discharge coefficient and quantity of discharge that cross the weir.
- Water depth at weir has major effect on Froude number and Reynolds number.
- The shape of weir and gate respectively play a vital role in estimation the value of dimensional and non-dimensional factors.

References

[1] Alhamid, A. A.: Analysis and formulation of flow through combined V-notch gate device, J. Hydraulic Res., 37(5), 697–705, 1999.
[2] Al-Saadi, A. K. I. : Study Coefficient of Discharge for a Combined Free Flow over Weir and under Gate for Multi Cases, Euphrates J. of Agric. Scie., 5 (4), 26-35, 2013.
[3] Fox, R. W. and McDonald, A. T. : Introduction to Fluid Mechanics, Fourth Edition, SI version Copyright © John Wiley and Sons, Inc, 1994.
[4] Hassan, F. A., Khassaf, S. I., and Omran, H. A. : Determining the coefficient of discharge due to Flow over Composite Weir and Below Gates, Asian Transactions on Engineering, 5(Issue 6), 2015.
[5] Khassaf, S. I, and Habeeb, M,: Experimental Investigation for flow through combined trapezoidal weir and rectangular gate, Int. J. of Scie. & Engrg. Res., 5(4), 809-813, 2014.
[6] Majcherek, H.: Submerged discharge relations of logarithmic weirs, J. Hydraulic Eng., 110(6), 840–846, 1984.
[7] Negm, A. M.: Characteristics of combined flow over weirs and under gates with unequal contractions, Advances in hydroscience and engineering, Tsinghua University Press, Beijing, 285–292, 1995.
[8] Negm, A. M.: Discharge prediction model for simultaneous underflow overflow, 6th Int. Symp. on Flow Modeling and Turbulence Measurements, 665– 670, 1996.
[9] Negm, A. M., Al-Brahim, A. M., and Al-Hamid, A. A.: Combined-free flow over weirs and below gates, J. Hydraulic Res., 40(3), 359–365, 2002.
[10] Obead, I. H, and Hamad, R. : Experimental Study of Coupled Flow through Combined Weir-Gate Structure, J. of Babylon Univ. Engrg. Scie., 22(1), 151-161, 2014.
[11] Qasim, R. M., Abdulhussein, I. A., Hameed, M. A., and Maatooq, Q. A.: Experimental Study of Coupled Parabolic Weir over Flow and Gate under Flow Rate", J. of Info. Engrg. & Application, 8(4), 34-42, 2018.
[12] Streeter, V. L., and Wylie, E. B. : Fluid Mechanics, First SI Metric Edition. Copy right©.,1989.

ISSN 1584 - 2665 (printed version); ISSN 2601 - 2332 (online); ISSN-L 1584 - 2665