

# Experimental Study of Composite Inclined Weir – Gate Hydraulic Structure

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*Abstract:* - Composite hydraulic structure is widely used in irrigation system which consists of two parts. The first part is responsible for overflow regime and is represented by a weir, whereas the second part is responsible for underflow regime and is represented by a gate. Both elements play significant role to control, measure, and divert the flow. So it dominates the hydraulic regimes of open channel or river with high responsibility and accuracy. The target of this study is to investigate the effect of the composite hydraulic structure installation at various inclination angles (from 45-135 degree) with the flume bed, which is horizontal, and adopt the normal position of composite device ( angle equal to 90 degree) as guide in discussion with various angles. Several experimental works were carried out in hydraulic laboratory flume at the Basrah Engineering Technical College under free flow condition with various geometrical dimensions of combined rectangular weir and rectangular gate in order to investigate the effect of inclination angle on major flow factors such as actual discharge, discharge coefficient, depth of water in downstream zone of flume, cross sectional area of flow that cross or pass the weir and gate respectively. Also, this study mentions the percentage of increase in discharge coefficient and variation in actual discharge, discharge coefficient and Reynolds Number with cross sectional area of flow that cross the gate.

*Key-Words:* - inclined composite structure, discharge coefficient, weir- gate

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## 1 Introduction

Composite weir-gate is a common and important structure that is used to control and regulate the flow in irrigation structures. The main advantages of this type of hydraulic structures are to overcome the problems of floating and deposited materials. The previous works were studying the composite weir-gate structure which installed perpendicular (right angle,  $\theta=90$ ) to the bed of the channel. According to our knowledge, we could not find literatures about inclined composite weir-gate structures; therefore, the literature in this study is restricted to the analysis of flow through inclined weirs. A lot of studies have analysed flow over rectangular side weir such as [1], [2], [3], [4], [5], and [6], whereas [7], [8], [9], and [10] have analysed the flow field over trapezoidal side weirs. The trapezoidal side weir is tested in [7]. The discharge coefficient of sharp crested trapezoidal side weirs is investigated in [8]. References [9] and [10] have studied the variation of discharge coefficient with the angle of inclination of trapezoidal weir plane with respect to the normal (standard) position of plane of weir for a sharp

crested trapezoidal weir. Most of the researchers have reported their study on establishing discharge coefficient in terms of weir head to weir (height/length) and skew angle. The most above researchers have calibrated their investigating weirs using data from other type of sharp crested weirs and this in turn limited the accuracy of their obtained results.

Several laboratory experiments on flow through inclined rectangular, trapezoidal, V-notch and inverted V-notch weirs have conducted in [11] and [12]. They developed a mathematical model to compute the head-discharge equation for each weir type and inclination. In all cases the results depend on the modeling and weir discharge coefficient as well as head index. These were developed on the basis of experimental values.

It is obvious that most of the investigators have studied the hydraulic characteristics of rectangular side weirs and the behavior of flow over sharp-crested trapezoidal side weirs whereas less attention has been given to the hydraulic characteristics of composite inclined weir-gate hydraulic structures.

In the present work an attempt is made to investigate the effect of the angle of inclination on the performance and characteristics of composite hydraulic structures. The rectangular weir - gate hydraulic structure is fixed inclined or vertical with respect to channel bed. Different hydraulic and geometric parameters are proposed to obtain the coefficient of discharge, actual discharge, downstream water level, and Reynolds number.

## 2 Fundamental of Fluid Mechanics

The theoretical discharge through combined weir-gate hydraulic structure under free flow condition is equal to the summation of theoretical discharge through gate and weir:

$$Q_{theor} = Q_w + Q_g \quad (1)$$

The theoretical discharge through weir is: (Streeter) [13]

$$Q_w = \frac{2}{3} \sqrt{2g} b h^{3/2} \quad (2)$$

and the theoretical discharge through gate is:, by using continuity equation (Streeter) [13]:

$$Q = V A \quad (3)$$

$$Q_g = V A = \sqrt{2gH} A g \quad (4)$$

In free flow condition

$$H = d + y + h \quad (5)$$

$$Q_{act} = c_d Q_{theor} \quad (6)$$

$$Q_{act} = c_d \left[ \frac{2}{3} \sqrt{2g} b h^{3/2} + \sqrt{2gH} A \right] \quad (7)$$

H: Water depth at the upstream of the gate opening

h: Head of water at sharp crest weir

y: Vertical distance between weir and gate

d: Height of gate opening

Ag: Flow cross-sectional area at the gate opening

b: Rectangular weir width

V: Velocity of flow through gate

$Q_{theor}$  : theoretical discharge

$Q_{act}$  : actual discharge

$c_d$  : discharge coefficient

## 3 Experimental Works

The experiments were carried out at the hydraulic laboratory flume located at the Basrah Engineering Technical College. A rectangular glass sided flume with a d dimension of 200cm length, 15cm depth and 7.5cm width. The discharge is measured using the volume method while the average water depth is measured by the point gage scale moves on the wall of the flume. Fig. 1 shows the definition of the inclined combined flow over rectangular weir and under rectangular gate that is considered in this study. Table 1 reviews selected dimensions of the rectangular model which fabricated from wood material and the corresponding results were obtained from experimental study conducted in laboratory. The following procedures are adopted in laboratory test [14].

1- The slope of the flume is always in a horizontal position.

2- The models were fixed into the flume at a distance 80cm from the beginning of the flume with arbitrary inclination with the horizontal bed.

3- The free flow condition is satisfied by removing the tail gate from the channel.

The above procedures were repeated for all models.

In the present study, five values of inclination angle were considered ( $\theta=45^\circ, 60^\circ, 90^\circ, 120^\circ$  and  $135^\circ$ ).

Then, forty five models were tested, nine models for each inclination angle, involving the following limitations:  $1.414 \leq y \leq 4$ ,  $1.414 \leq d \leq 4$ ,  $b=2$  cm,  $0.707 \leq h_u \leq 3$ ,  $1.414 \leq A_w \leq 4$ ,  $2.828 \leq A_g \leq 8$ , where  $A_w=b.h$  is the weir cross sectional area.

Models are made of wood sheet 5mm thick beveled along all the edges at  $45^\circ$  with sharp edges of thickness 1mm (Qasim et. al., 2018). Models are fixed to flume using plexiglass supports. Additional supports have used to satisfy the necessary of inclination angle. The flume and model material have selected according to available laboratory facilities. In each test, combined actual discharge,

Table 1. The tested model dimensions, details and results of selected weir and gate angle of inclination

Angle of Inclination	$h_u$ (cm)	y (cm)	d (cm)	H (cm)	$A_w$ (cm <sup>2</sup> )	$A_g$ (cm <sup>2</sup> )	$R_N$	$h_d$ (cm)	$Q_{act.}$ (l/sec.)	Cd
45	1.414	2.12	2.12	5.657	2.288	4.242	5911	2.50	0.4433	0.812
60	1.732	2.59	2.59	6.928	3.464	5.196	8577	3.50	0.6433	0.869
90	2.00	3.00	3.00	8.00	4.00	6.00	9852	1.80	0.7389	0.804
120	1.732	2.59	2.59	6.928	3.464	5.196	8350	4.06	0.6263	0.846
135	1.414	2.12	2.12	5.657	2.288	4.242	7268	3.55	0.5450	0.998

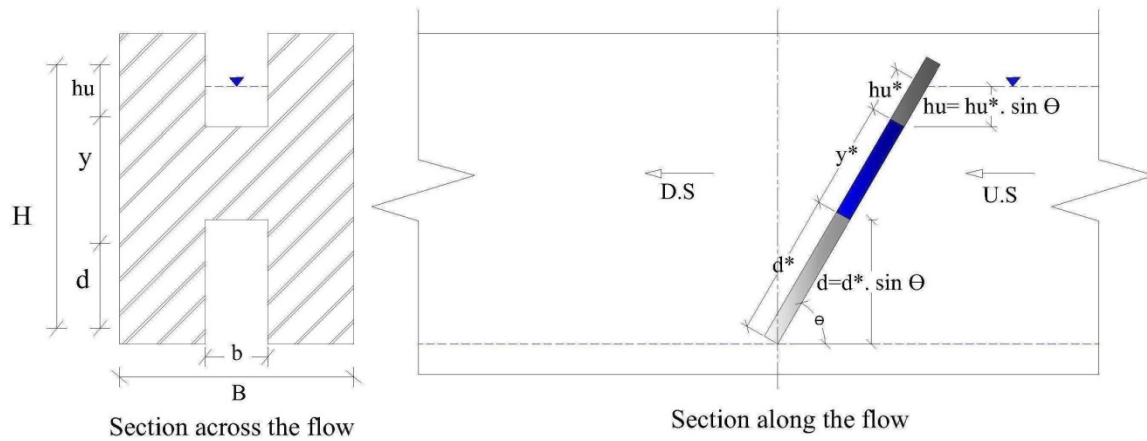


Fig. 1. Arrangements of inclined composite rectangular weir-gate structure

$Q_{act.}$ , head over the weir,  $h_{ut}$ , downstream flow depth,  $h_d$ , and upstream flow depth,  $H$ , were measured under free flow conditions.

#### 4 Results and Discussion

The composite hydraulic structure have significant role in controlling and measuring the flow, distributing and divert the flow path, and controlling the flow direction. Actually it is preferred to construct the composite hydraulic structure in a normal position ( $90^\circ$ ) at the channel or river. This arrangement is commonly used in the field and easy to achieve without any complication. However, if we attempt to construct this structure in an inclined position, with respect to horizontal bed of channel or river bed in order to study the influence of many hydraulic factors and geometrical aspects on the major function of combined hydraulic structure, which are represented by discharge quantity and discharge coefficient, we encounter increase in a number of factors and decrease in other factors. This will reflect on hydraulic response of composite hydraulic structure. Therefore many experimental studies are carried out in hydraulic laboratory to investigate the effect of inclination angle on the hydraulic properties and geometrical factors. It is clear that the relationship between discharge coefficient and water head above weir is consider inversely regardless of the shapes of weir, gate, and composite weir and gate, and inclination angle of composite hydraulic structure in flume or channel in the field. Fig. 2 shows that the discharge coefficient decreases with increasing of water head value above weir. Also, this figure shows some variations occur in style of relationship and this is due to the effect of inclination angle of composite structure and interaction between flow

velocities through the weir and gate. It is evident that the flow rate (discharge) has direct proportional with water head above the weir. So as water head increase the water discharge must be increase and inversely is correct.

Fig. 3 shows that the discharge values increase as water head above weir increase regardless of the composite hydraulic structure inclination angles with horizontal axis when the horizontal axis represent the bed of the flume in laboratory or bed of channel in the field.

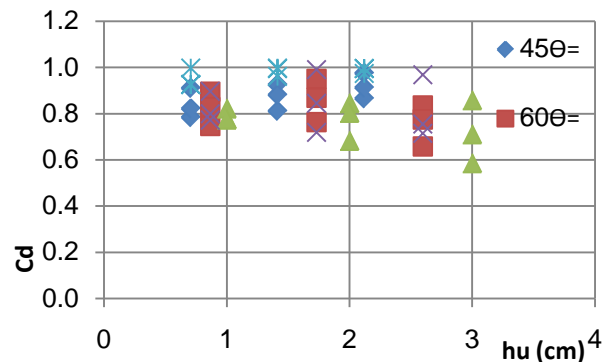


Fig. 2 Variation of Coefficient of discharge with weir water level

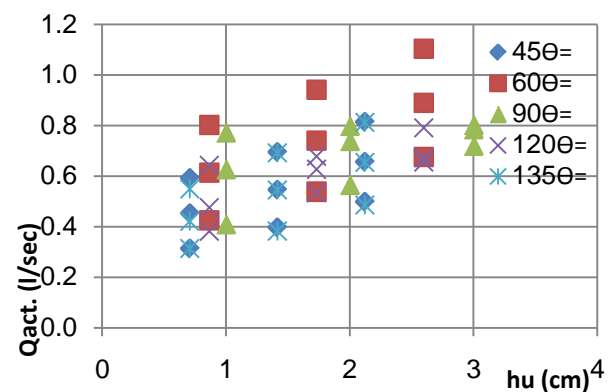


Fig. 3 Variation of Actual Discharge with Weir Water Level

Practically raising or falling of the downstream water depth depends primarily on the upstream water depth and the installation of the composite hydraulic structure. Many options can be implemented in the installation of the composite hydraulic structure and two options were adopted in this study. The first option is installing the device in a normal position, whereas the second one is installing the device in an inclined position. From Fig. 4, for inclination angle of  $45^\circ$ , the water depth above sharp crest of weir is observed to be small (the weir works as chute) therefore the raise of water in downstream region depends on the depth of water inside the gate. For inclination angles of  $60^\circ$  and  $90^\circ$  (normal position), the stream flow that cross or pass the weir and gate respectively, operate together in order to increase the downstream flow depth. The experimental results of angle  $90^\circ$  appear in Fig. 4 are lower than that of angle  $60^\circ$  due to the effect of the interaction between the weir and gate flow velocities. For angle  $120^\circ$ , the weir and gate work at high efficiency and large quantity of discharge flows through the weir and gate. For angle  $135^\circ$  which is approximately the same hydraulic behavior of angle  $120^\circ$  and this clearly appear from Fig. 4. This causes a high rise in the downstream water depth comparing with the other inclination degrees.

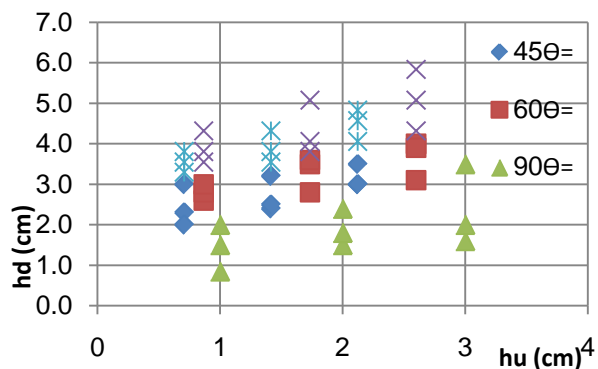


Fig. 4 Variation of Downstream water Level with Weir Water Level

Fig. 5 reviewed the relationship between the discharge and the dimensionless weir area parameter  $A_w/HB$  where B is considered as a constant and represents the flume width, while H and  $A_w$  are considered as variables; where H represents the upstream water depth or vertical depth of water measured from water surface to the flume bed, and  $A_w$  represents the flow cross-sectional area that passes over the weir. According to the continuity equation, the discharge has direct proportional to the flow cross-sectional area, so the increase in any variable will reflect on the other. Fig. 5 shows that

the actual discharge and the dimensionless weir area  $A_w/HB$  increase regardless of the inclination angle of the composed hydraulic structure. It's worth mentioning that the total upstream water depth (H) has minor effect on discharge, whereas flow cross-sectional area of flow and the weir discharge affect the water head above the weir. This is because of the weir flow velocity which depends on the water head above the sharp crested weir and this will reflect on flow cross-sectional area that across the weir due to inversely proportional of flow velocity and flow cross-sectional area according to the continuity equation. So it is evident that the increase in flow velocity which leads to decrease in flow cross-sectional area and the inverse is correct.

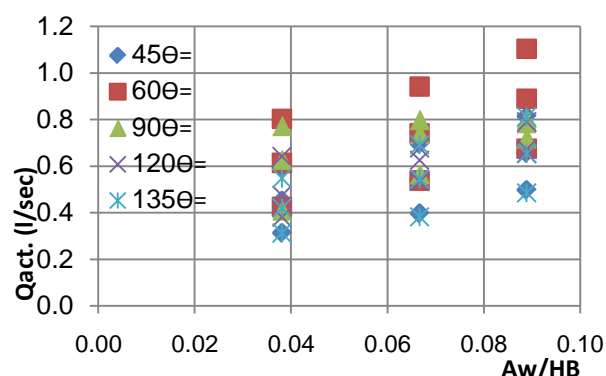


Fig. 5 Variation of Actual Discharge with Area of Weir ( $A_w/BH$ )

The relationship between actual discharge and dimensionless parameter of normal distance between gate and weir ( $y/H$ ) were shown in Fig. 6. This figure indicated that the discharge value decreases as the ( $y/H$ ) value increases. So, Fig. 6 showed an inversely relationship between the discharge and the ( $y/H$ ) regardless of the location of the composite hydraulic structure with respect to flume bed. The factors that dominate this problem are the upstream flow depth (H), geometrical distance between the weir and the gate (y) (which considered a perpendicular distance), flow depth over sharp crested weir ( $h_u$ ), and water depth at gate (d), where ( $H=h+y+d$ ) as shown in Fig. 1. In this condition (h) and (d) are considered constants, only (y) varies with the flow. Therefore, (H) is directly proportional to the y-value. The y-value represents the vertical distance between the weir and the gate it depends on the inclined distance between the weir and the gate and on the inclination angle of the combined device. As the y-value increases, the inclined distance between the weir and the gate will increase and this makes

more restriction to the flow which leads to decrease in discharge quantity.

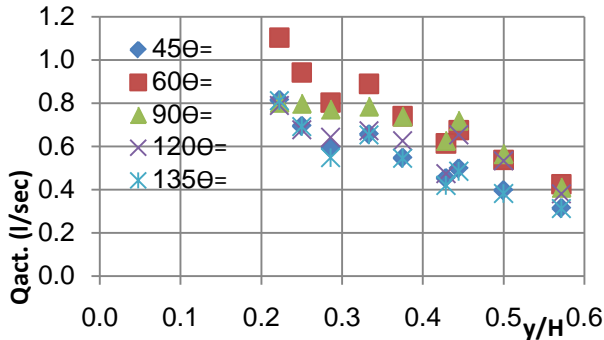


Fig. 6 Variation of Actual Discharge with Distance between Weir and Gate (y/H)

Fig. 7 showed the relation of actual discharge versus average flow velocity, apparently a poor correlation because of randomly distribution of collected data from the experimental runs. This happened due to many reasons that have direct and indirect effects on the hydraulic behavior of the composite hydraulic device. These reasons include; interaction between the overflow and underflow velocities, the influence of inclination angle, and the influence of the geometrical properties, such as y-value, regardless of the relation between the discharge and flow velocity from the continuity equation.

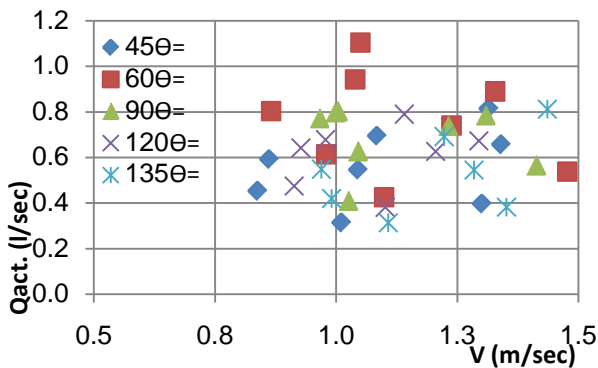


Fig. 7 Variation of Actual Discharge with Average Velocity

Fig. 8 shows the relation between the  $Q_{act}$  and the dimensionless gate cross sectional area  $A_g/HB$  where B is constant and represent the flume width while H and  $A_g$  are considered variables taken in consideration H represents the water depth at upstream of flume or vertical depth of water measured from water surface to bed of flume and  $A_g$  represents the area of flow through gate or cross sectional area of flow that passes the gate. It appears from this figure that there is an inversely relationship between discharge and flow cross-

sectional area across the gate. This is because of high effect of water depth in stream of flume (H) which has a great effect on flow velocity across the gate and from continuity equation the relationship between flow velocity and cross sectional area of flow is considered inversely proportional and the discharge has minor influence on flow cross sectional area.

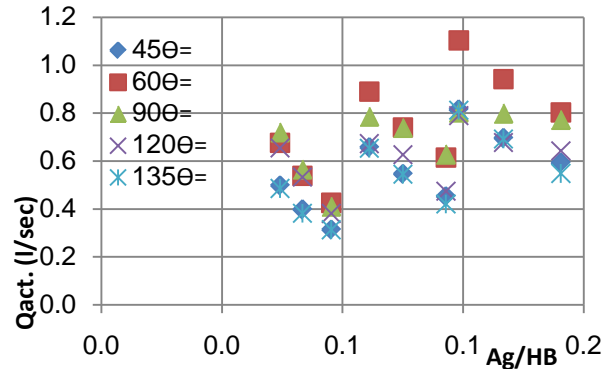


Fig. 8 Variation of Actual Discharge with Area of Gate ( $A_g/HB$ )

For specific data that collected from our experimental runs, some relationships were sketched to get better explanation about the link between hydraulic parameters that control the behavior of the hydraulic system taking into consideration the effect of inclination angle of the combined hydraulic structure. Fig. 9 showed direct proportional between the discharge and dimensionless weir cross-sectional area  $A_w/HB$ . Incremental increasing in weir water head has a great effect on discharge value passes over the weir comparing with the discharge value passes through the gate. So any small incremental increase in h value will increase the weir cross-sectional area and this will be reflected directly on increasing in actual discharge.

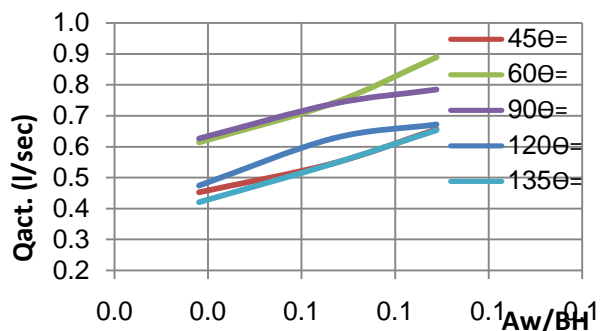


Fig. 9 Variation of Actual Discharge with area of weir

Also, Fig. 10 shows inversely proportional between discharge and (y/H). And Fig. 11 review inversely



relationship between discharge and cross sectional area of flow cross the gate. Table (2) shows the variation of  $Q_{act}$  with  $(A_g/BH)$  dimensionless parameter for different inclination angles of hydraulic structure with flume bed. It can be seen from this table that the actual discharge values change with inclination angles. It is shown that the discharge quantity decrease with decreasing in angle below 90 degree except there is approximately some converge in discharge when angle equal to 90 degree and 60 degree, if we consider the normal position ( $90^\circ$ ) of composite hydraulic structure as a guide. The increase in discharge occurs when weir and gate work together and the water cross the composite hydraulic structures with high efficiency and no water retain beside the composite hydraulic structure for long duration. Also it is obvious from table (2) as the inclination angle increases above  $90^\circ$  the discharge quantity will decrease as compare with normal position. Table (3) shows the variation in  $C_d$  with  $(A_g/BH)$  for different inclination angles.

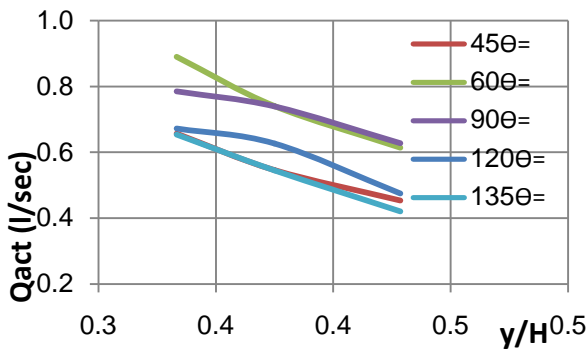


Fig. 10 Variation of Actual Discharge with perpendicular distance between weir and gate ( $y/H$ )

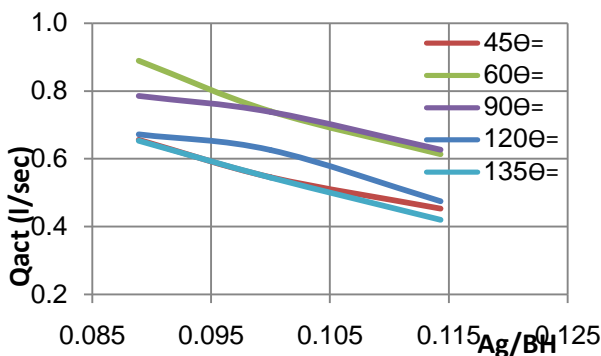


Fig. 11 Variation of Actual Discharge with Area of Gate

It is shown from this table that the discharge coefficient values increase when the inclination angle values are less or greater than  $90^\circ$  for all  $(A_g/BH)$  values. If we consider the normal position of composite hydraulic structure as a guide,

table (4) shows the percentage increase in coefficient of discharge. Table (5) shows the variation of Reynolds number with  $(A_g/BH)$  for different inclination. This table showed that the flow in flume is considered turbulent because of  $R_e > 2000$  so the inclination angle has no effect on flume flow regime.

Table 2. Actual Discharge with Area of Gate

$A_g/BH$	$\theta=90$	$\theta=45$	$\theta=60$	$\theta=120$	$\theta=135$
0.0762	0.4100	0.314	0.425	0.3815	0.3133
0.0667	0.5653	0.397	0.539	0.5335	0.3823
0.0593	0.7200	0.499	0.676	0.6545	0.4857
0.1143	0.6272	0.453	0.614	0.4747	0.4204
0.1000	0.7389	0.546	0.740	0.6263	0.5451
0.0889	0.7853	0.657	0.890	0.6726	0.6536
0.1524	0.7725	0.593	0.803	0.6424	0.5484
0.1333	0.7986	0.695	0.942	0.6777	0.6918
0.1185	0.8029	0.815	1.104	0.7902	0.8123

Table 3. Discharge Coefficient with Area of Gate

$A_g/BH$	$\theta=90$	$\theta=45$	$\theta=60$	$\theta=120$	$\theta=135$
0.0762	0.777	0.911	0.895	0.897	0.998
0.0667	0.846	0.926	0.950	0.991	0.962
0.0593	0.859	0.976	0.835	0.969	0.974
0.1143	0.823	0.784	0.829	0.773	0.928
0.1000	0.804	0.812	0.869	0.846	0.998
0.0889	0.711	0.866	0.776	0.756	0.995
0.1524	0.775	0.822	0.747	0.800	0.926
0.1333	0.683	0.882	0.764	0.719	0.995
0.1185	0.586	0.913	0.659	0.716	0.997

Table 4. Discharge Coefficient Increase with Area of Gate

$A_g/BH$	$\theta=45$	$\theta=60$	$\theta=120$	$\theta=135$
0.0762	0.1727	0.1521	0.1545	0.2849
0.0667	0.0946	0.1230	0.1709	0.1374
0.0593	0.1363	-0.0276	0.1280	0.1345
0.1143	-0.0469	0.0071	-0.0609	0.1272
0.1000	0.0091	0.0803	0.0517	0.2407
0.0889	0.2175	0.0905	0.0628	0.3997
0.1524	0.0608	-0.0363	0.0318	0.1940
0.1333	0.2911	0.1187	0.0530	0.4569
0.1185	0.5581	0.1245	0.2212	0.7015

Table 5. Reynolds Number with Area of Gate

$A_g/BH$	$\theta=90$	$\theta=45$	$\theta=60$	$\theta=120$	$\theta=135$
0.0762	5467	3812	5076	5087	4177
0.0667	7538	4906	6822	7113	5098
0.0593	9600	6486	7524	8727	6476
0.1143	8362	4739	6787	6329	5605

0.1000	9852	5911	8578	8351	7268
0.0889	10471	7581	9202	8969	8715
0.1524	10300	6497	8000	8565	7313
0.1333	10648	8174	9600	9036	9224
0.1185	10705	9917	9701	10536	10830

For a constant composite hydraulic structure, the projected area between the weir and gate for inclined device is less than that for normal vertical device. So thrust force exerted by flow on inclined device is less than that on normal vertical device for a same flow characteristic. Hence it can be concluded that the inclined hydraulic structure is more stable comparing with the normal vertical one.

## 5 Conclusion

A set of experimental works have been conducted to investigate the effect of inclined composite inclined hydraulic structures on flow characteristics. Numerous points were concluded from this study. Firstly, the water head above the sharp crested weir has major effect on the assessment of discharge coefficient value of the composite hydraulic structure. It was also noted that the actual discharge value increases with increasing in the sharp crested weir water head due to direct proportional between them. Another observation would be that the downstream water depth depends primarily on the sharp crested weir water head and the inclination angle of the composite structure. Moreover, the actual discharge is directly proportional to flow cross-sectional area that crosses the weir. Another conclusion was that the geometrical dimensions have played a vital role in controlling the actual discharge value that passes through the composite hydraulic structure during its operational life. It was also observed that the interaction between overflow and underflow velocities has major effect on establishing the relationship between actual discharge and flow velocity that crosses the combined device. An inverse relationship between actual discharge and gate cross sectional area was discovered. The discharge coefficient values have increased when the values of the inclination angle less than or greater than 90° for all values of the gate cross-sectional area. This increase in the discharge coefficient value can be considered as a non-uniform. Finally the inclination angle has no effect on flow regime through the composite device and the flow always in turbulence condition.

## References:

- [1] Henderson. F.M., *Open Channel Flow*, Macmillan Publishing Co., Inc, New York, 1964.
- [2] Subramanya, K. and Awasthy, S.C., "Spatially varied flow over side weirs", *J. of Hydraulic Engineering, ASCE*, Vol. 98, No.1, 1972, pp. 814- 819.
- [3] Nadesamoorthy, T. and Thomson, A., "Discussion of spatially varied flow over side weirs," *J. of Hydraulic Engineering, ASCE*, Vol. 98, No. 12, 1972, pp. 2234-2235.
- [4] Rangaraju, K.G., Prasad, B. and Gupta, S., "Side weirs in rectangular channels," *J. of Hydraulic Engineering, ASCE*, Vol. 105, No. 5, 1979, pp. 547-554.
- [5] Hager, W.H., "Lateral outflow over side weirs," *J. Hydraulic Engineering, ASCE*, Vol. 113, No. 4, 1987, pp. 491-504.
- [6] Singh, R., Manivannan, D. and Satyanarayana, T., "Discharge coefficient of rectangular side weirs," *J. of Irrigation and Drainage Engineering, ASCE*, Vol. 120, No. 4, 1994, pp. 812- 819.
- [7] Ramamurthy AS, Tim US, Carballada L., "Lateral weirs in Trapezoidal channels", *J. Irrig & Drain Eng.*, Vol. 112, No. 2, 1986, pp. 130-7
- [8] Rahimpour M, Keshavarz Z, Ahmadi M., Flow over trapezoidal side weir, *Flow Measurement and Instrumentation*. Vol. 22, No. 6, 2011, pp.507-10.
- [9] Hadis Haddadi, and Majid Rahimpour. A discharge coefficient for a trapezoidal broad crested side weir in subcritical flow. *Flow Measurement and Instrumentation*, Vol. 26 , 2012, pp. 63-67.
- [10] Shesha Prakash, M. N. and Shivapur, A. V., Enhancing Discharge capacity of a Trapezoidal Weir with Inclination, *Proc. of Hydro-2004, National Conference on Hydraulics and Water Resources, Sponsored by Indian Society for Hydraulics, held at Visvesvaraya National Institute of Technology, Nagpur from Dec. 27-28, 2004.*
- [11] Shesha Prakash, M. N. and Shivapur, A. V., Study on Discharge Characteristics of Sharp Crest inclined Trapezoidal Notch,

- ISH J. of Hydraulic Engineering*, Vol. 12, No. 2, 2006, pp. 118-130.
- [12] Shesha Prakash, M. N., Ananthayya, M. B. and Gicy Koor, Inclined Trapezoidal Weir: Flow Modelling, International, *J. of Advanced Engineering and Technology*, IJAET/Vol. II/ Issue IV, 2011.
- [13] 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*, Vol. 8, No. 4, 2018, pp. 34-42.
- [14] Streeter, V. L., and Wylie, E. B. *Fluid Mechanics*, First SI Metric Edition. Copy right©., 1989.