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Energy Loss Through Combined Weir Above Circular Gate

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ABSTRACT
Weirs are widely used as discharge measuring device in laboratories, industries and irrigation channels, studied combined orifice-weir flow is a complex phenomenon in hydropower and the discharge capacity of a structure which affects the safety of the structure. In this paper, an experimental study investigate total energy loss through combined weir with different relative width, relative height and gate opening with different relative diameter to improve characteristics of hydraulic jump and reduction scour from weirs. The result showed that, maximum relative energy loss at relative combined weir width = 0.13 but the relative minimum = 0.23, maximum relative energy loss at relative combined weir height =0.18 but the relative minimum =0.12 and maximum relative energy loss at the relative diameter of gate opening in combined weir = 0.2 but the relative minimum = 0.4. Measured and predicted data were agree well and gave standard error = 0.012, correlation coefficient = 97%. Predicted equation (4) for relative energy loss using multiple linear regressions data agree well with the measured data Boundary condition for (Initial Froude number = 1.3 to 1.5, relative width of combined weir = 0.13 to 0.23, relative height of combined weir = 0.12 to 0.22 and relative diameter of gate opening in combined weir = 0.2 to 0.4).

Keywords: *Combined weirs, energy loss, gats, linear regressions, measured data.*

1. Introduction

Weirs have many applications in the field of hydraulic engineering, used for discharge measurement, flow diversion, depth regulation, and dissipation of excess energy (Falvey, H. 2003). Kindsvater C.E. and Carter R.W. (1957) studied extensive rectangular sharp crested weirs. Swamee P.K. (1988) proposed a generalized weir equation for sharp-crested, narrow-crested, broad-crested and long-crested weirs by combining the equations obtained from previous works. Negm M A. et al. (2002) discussed characteristics of the combined flow over weirs and below gates. Aydin I. et al. (2006) showed that combined sharp-crested weirs have been widely used for measuring discharges in open channels accurately with a reasonable sensitivity over a wide flow range. Hayawi H. A. et al (2009) investigated coefficient of discharge for a combined hydraulic measuring device. Al-Saadi A. K. (2013) studied the hydraulic characteristics of different combined weirs (rectangle, v-notch, and semi-circular), Fadhel A. (2015) investigated experimentally value of discharge coefficient (Cd) due to flow over combined sharp crested weir. Shaymaa A. M. et al. (2016) studied experimentally a new performance was added to this weir and numerically using FLUENT program. Abd el- Aal G. M., et al. (2018) investigated experimentally energy dissipation through stepped spillways using breakers. The results showed that the stepped spillway with breakers type had dissipated more energy than the classical stepped spillway type. Rafi M. et al (2018), investigated overlapping between weir and gate having a parabolic shape. Shaker A. J. (2018) studied reducing suspended material and its deposition in the combined weir. Zong-Fu Fu et al. (2018) studied combined orifice weir and effect discharge capacity on the safety of the structures. Bshkoj S. and Shaker A. (2020) investigated combined hydraulic structure experimentally and numerically which showed that discharge coefficient between (0.52-0.58). Helal E. et al., (2020) simulate submerged hydraulic jumps with and without bed water jets using Computational fluid dynamics (CFD) modeling. This Simulated results indicated that the bed water jets improved the efficiency of the submerged hydraulic jumps by up to 85.4% and reduced the submerged jump lengths by up to 59% compared to the non-jetted system. Elsayed H. et al., (2021), studied experimentally effect of different regulator gate operation schemes on scour hole formation downstream under free-flow conditions. The result showed that most favorable operation case was with all five open gates opened, while the least favorable operation case was with only the side gate opened. Tanimu B. et al. (2021) studied experimentally effect of varying angle of a trapezoidal weir coupled with a below semi-circular gate. Al sayed

I. D. (2022) investigated the flow passing through V-notch sharp crested weir and inverted V-shaped sharp gate in straight channel. In this paper investigate energy loss though combined weir with different wide, height and gate opening with different diameter to dissipate energy though hydraulic jump downstream weir at stilling basin to reduce scour at hydraulic structures.

2. Experimental Study

The experimental work was carried out in the Hydraulics and water Engineering Laboratory, Faculty of Engineering, Benha University, the flume width was of 0.4 m, height of 0.6 m, and length of 15.0 m as shown in figure 1, combined weir with gate opening used as shown in photo 1. A flow meter was installed to measure the discharge which feeding the flume, Table 1 showed definition of the experimental models "problem definition"

Table 1: Definition of the experimental models "problem definition"

Discharge (L/s)	6 to 30	Initial depth of hydraulic jump (cm)	2 to 6
Width of the upper notch of the combined weir $W_2 = W_3$ (cm)	13.3	Sequent depth of hydraulic jump (cm)	5 to 15
Angle of the crest of the combined weir (θ)	45	Initial Froude number of hydraulic jump	1.3 to 1.5
Water depth at upstream of combined weir	32 to 52	Final Froude number of hydraulic jump	0.3 to 0.45

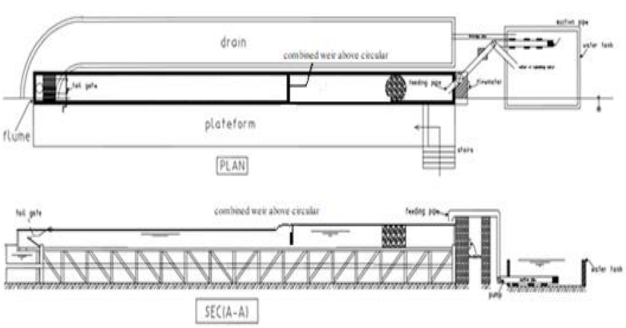


Figure. 1 Plan and elevation of the model in flume

Photo 1 Combined weir with below circular gate model

3. Theoretical Study

Using dimensional analysis method for the experimental parameters as showed in Figure 2, the different variables affecting the energy loss through combined weir with below circular gate can be expressed as a function of the following:

$$\frac{E_L}{E_u} = f\,(H, y_u, y_1, y_2, y_d, Z, D, B, W_1, W_2, W_3, g, v, \rho, \mu, \sigma, \theta, q) \quad \ldots\ldots(1)$$

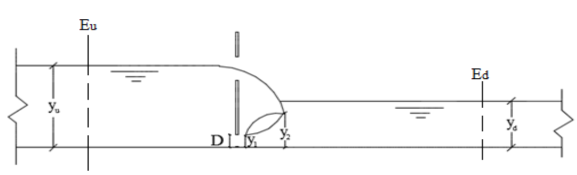
Applying the Buckingham theorem, choosing (ρ, W, and g), as repeating variables, the number of Π groups = 18-3 = 15 Π.

The above groups can be rearranged, and then the following fundamental relationship can be obtained, the Main groups may be as:

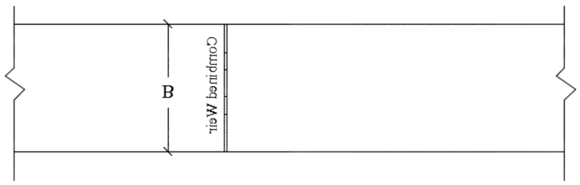
$$\frac{E_L}{E_u} = f\left(\begin{matrix}\frac{W_1}{W}, \frac{W_2}{W}, \frac{W_3}{W}, \frac{y_u}{W}, \frac{Z}{W}, \frac{D}{W}, \frac{B}{W}, \frac{y_u}{W}, \frac{y_1}{W}, \frac{y_2}{W} \\ , F_n, R_n, W_n, \theta, \frac{q}{w^{1.5} g^{0.5}}\end{matrix}\right) \ldots\ldots(2)$$

In which R_n and W_n are Reynolds and Weber numbers respectively and assumed to be neglected at tested parameters, (B, θ) are the constant parameters, Eq. (2) may be rewritten as;

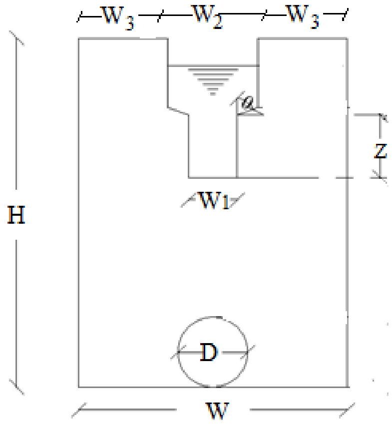
$$\frac{E_L}{E_u} = f\left(Fn, \frac{W_1}{W}, \frac{z}{H}, \frac{D}{W}, \frac{q}{w^{1.5} g^{0.5}}\right) \ldots\ldots(3)$$



(a)



(b)



(c)

Figure 2 Definition sketch for the experimental models. (a) Elevation, (b) plan and (c) combined weir.

4- Analysis and discussion:

4-1 Effect of combined weir width (W_1/W) on the energy loss

The total loss through combined weir from upstream to downstream (E_l) as shown in figure 2. The effect of width of combined weir on the relative energy loss was investigated experimentally in which the relative combined weir width (W_1/W) was changed to be 0.13, 0.18 and 0.23. The relationship between the relative energy loss (E_L/E_u) and initial Froude number (Fn_1) is shown in Figure 3 for different relative combined weir width (W_1/W). This figure shows that, the relative energy loss (E_L/E_u) decreases as initial Froude number (Fn_1) increases, also explains that the relative energy loss (E_L/E_u) increases with decreasing of the relative combined weir width (W_1/W). Figure 4 clear the relation between the relative energy loss (E_L/E_u) and sequent Froude number (Fn_2) and showed that increasing sequent Froude number (Fn_2) lead to increasing relative energy loss ($E_L/E_{u.s}$). Maximum value of energy loss (E_L/E_u) at relative combined weir width (W1/W = 0.13) and minimum value of energy loss (E_L/E_u) at relative combined weir width (W_1/W = 0.23) at initial Froude number (Fn_1 =1.35) as shown in Figure 5. The analysis of previous results are increasing width ratio lead to increasing cross section area of water lead to increase the discharge coefficient so energy dissipation increased.

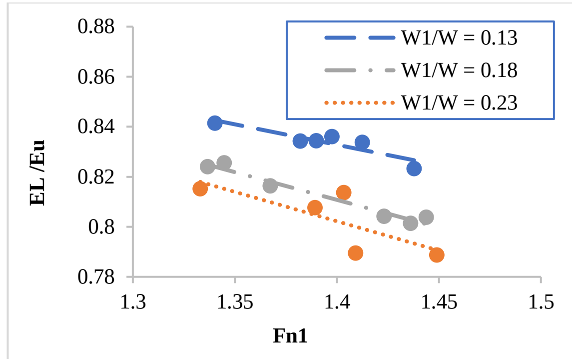


Figure 3 Relationship between (E_L/E_u) and Fn_1 at different relative combined weir width.

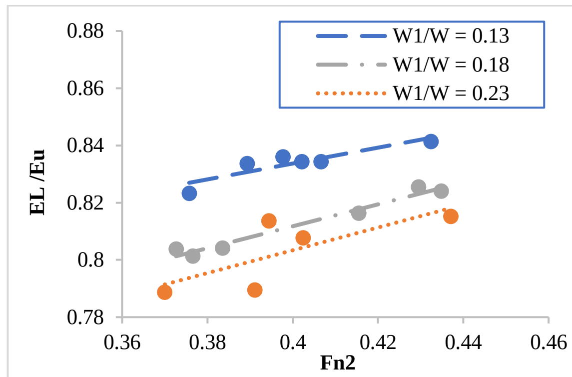


Figure 4 Relationship between (E_L/E_u) and Fn_2 at different relative combined weir width.

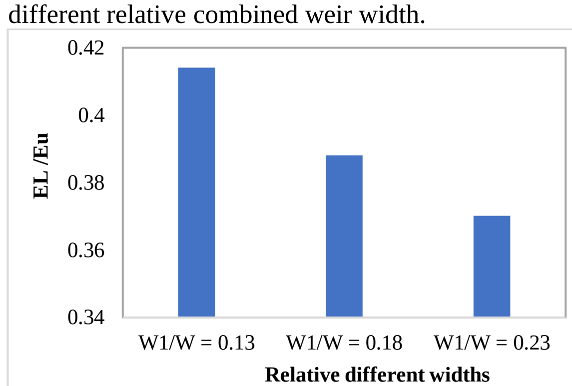


Figure 5 Relationship between (E_L/E_u) and different relative combined weir width at Fn_1 = 1.35

4-2 Effect of combined weir height (Z/H) on the energy loss

For relative combined weir width (W_1/W = 0.13), effect of height of combined weir on the relative energy loss was investigated experimentally in which the relative combined weir height (Z/H) was changed to be 0.12, 0.18 and 0.22. Figure 6 for different relative combined weir height (Z/H). This figure shows that, the relative energy loss (E_L/E_u) decreases as initial Froude number (Fn_1) increases, Figure 7 clear the relation between the relative energy loss (E_L/E_u) and sequent Froude number (Fn_2). This figures show that maximum relative energy loss (E_L/E_u) at relative combined weir height (Z/H = 0.18) but minimum relative energy loss (E_L/E_u) at relative combined weir height (Z/H = 0.12). Figure 8 showed that values of relative energy loss (E_L/E_u) and different relative combined weir height (Z/H) at initial Froude number (Fn_1 = 1.48). The analysis of previous results are increasing height ratio lead to increasing cross section area of water lead to increase the discharge coefficient so energy dissipation increased.

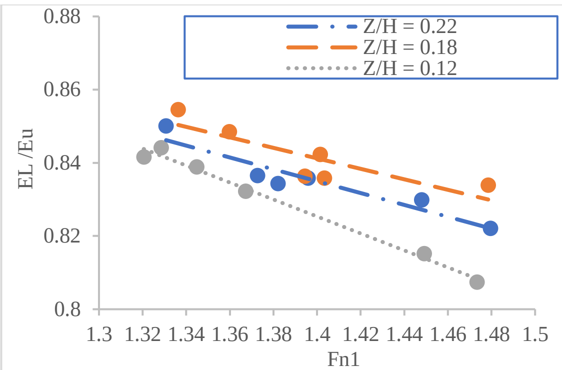


Figure 6 Relationship between (E_L/E_u) and Fn_1 at different relative combined weir height.

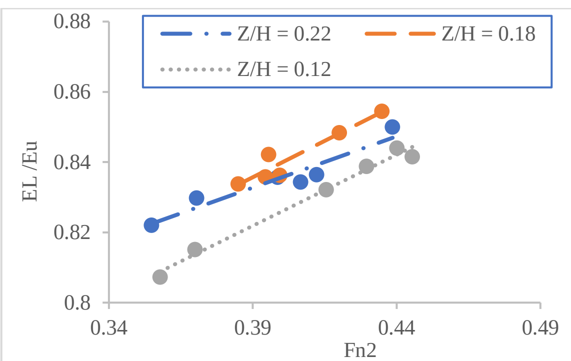


Figure 7 Relationship between (E_L/E_u) and Fn_2 at different relative combined weir height.

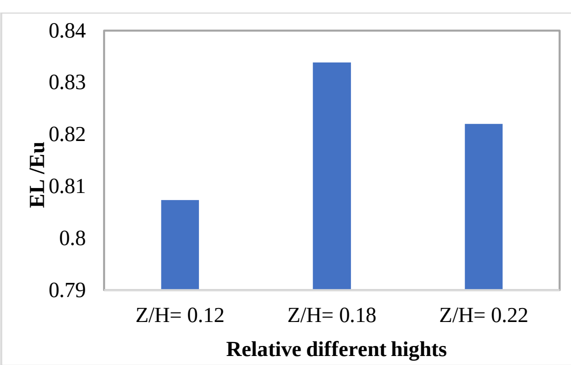


Figure 8 Relationship between (E_L/E_u) and different relative combined weir height at Fn_1 = 1.48

4-3 Effect of gate diameter in combined weir (D/W) on the energy loss

The previous effects of wide and height for combined weir was without gate opening but this effect study different diameter of gate opening in combined weir (D/W) was changed to be 0.2, 0.3 and 0.4. Figure 9 show the relationship between the relative energy loss (E_L/E_u) and initial Froude number (Fn_1) and Figure 10 show the relationship between the relative energy loss (E_L/E_u) and sequent Froude number (Fn_2)) for different diameter of gate opening in combined weir (D/W). this figures clear that the relative energy loss (E_L/E_u) decreases as Froude number increases, and relative energy loss (E_L/E_u) increases with decreasing of the relative diameter of gate opening in combined weir (D/W). Figure 11 show that maximum value of relative energy loss (E_L/E_u) at relative diameter of gate opening (D/W) = 0.2 but minimum value of relative energy loss (E_L/E_u) at relative diameter of gate opening (D/W) = 0.4 at initial Froude number (Fn_1 = 1.3). The analysis of previous results are increasing diameter ratio of gate lead to decreasing cross section area of water lead to increase the discharge coefficient so energy dissipation increased.

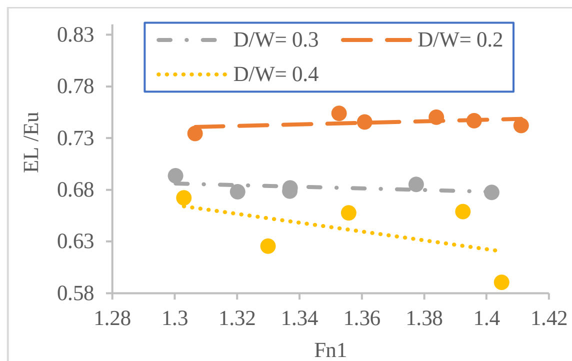


Figure 9 Relationship between (E_L/E_u) and Fn_1 at different relative diameter of gate opening.

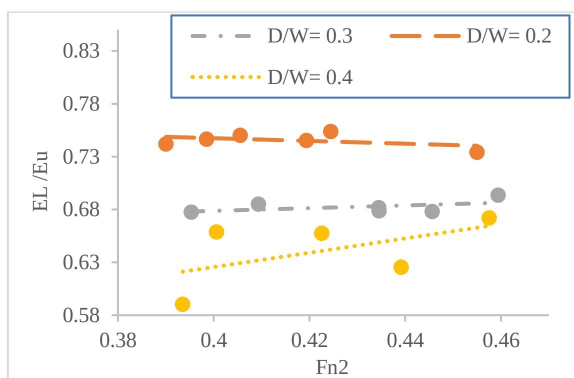


Figure 10 Relationship between (E_L/E_u) and Fn_2 at different relative diameter of gate opening.

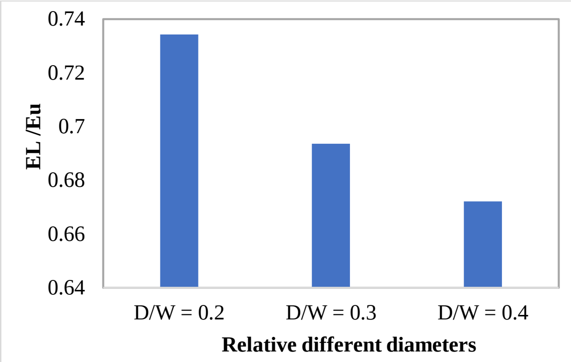


Figure 11 Relationship between (E_L/E_u) and different relative diameter of gate opening at $Fn_1 = 1.3$

5- Statistical analysis

Regression analysis was applied for the relative energy loss with other independent parameters. So, predicted equations for different cases were created as follow:

$$\frac{E_L}{E_u} = 1.11 - 0.17\ \mathrm{Fn_1} - 0.34\left(\frac{W_1}{W}\right) + 0.06\left(\frac{Z}{H}\right) - 0.46\left(\frac{D}{W}\right) \quad (4)$$

The correlation coefficients of Equation (4) is 97% and stander errors is 0.012, this equation applicable for boundary conditions are (Fn_1 = 1.3 to 1.5, $\frac{W_1}{W}$ = 0.13 to 0.23 , $\frac{Z}{H}$ = 0.12 to 0.22 and $\frac{D}{W}$ = 0.2 to 0.4).The predicted and measured data of relative energy loss presented in Figure 12, It was found that the predicted equation express well the measured data For previous boundary conditions.

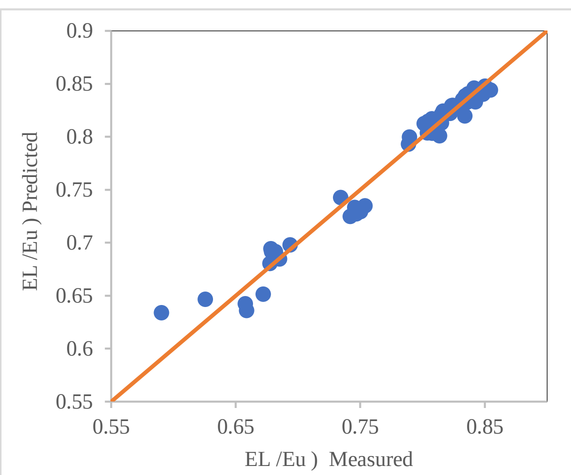


Figure 12 Comparison between Predicted and Measured values of (Eq.4) for the relative energy loss (E_L/E_u)

6- Conclusions

In the present paper, experimental studies are implemented on combined weir above circular gate, it was found that:

1. The relative energy loss (E_L/E_u) decreases as increasing the initial Froude number (Fn_1).
2. The relative energy loss (E_L/E_u) decreases as increasing the sequent Froude number (Fn_2).
3. The relative energy loss (E_L/E_u) increases with decreasing of the relative combined weir width (W_1/W).
4. Maximum relative energy loss at relative combined weir width = 0.13 but minimum relative energy loss at relative combined weir width = 0.23
5. Maximum relative energy loss (E_L/E_u) at relative combined weir height (Z/H = 0.18) but minimum relative energy loss (E_L/E_u) at relative combined weir height (Z/H = 0.12).
6. The relative energy loss (E_L/E_u) increases with decreasing of the relative diameter of gate opening in combined weir (D/W).
7. Maximum relative energy loss at the relative diameter of gate opening in combined weir = 0.2 but minimum relative energy loss at the relative diameter of gate opening in combined weir = 0.4
8. Agree well between predict and measured data so correlation coefficients of Equation (4) is 97% and stander errors is 0.012 for Equation (4).

List of abbreviations

E_L: Energy Loss = $E_u - E_d$
E_u: Energy at upstream of combined weir
E_d: Energy at downstream of combined weir
H: the total height of the combined weir
y_u: water depth at upstream of combined weir
y_1: water depth at initial hydraulic depth
y_2: water depth at sequent hydraulic depth
y_d: water depth at downstream of combined weir
Z: is the height of the lower notch
D: diameter of the circular gate
W_1: width of the lower notch of the combined weir
$W_2 = W_3$: width of the upper notch of the combined weir
g: the gravitational acceleration
ɵ: angle of the crest of the combined weir
B: width of the flume
ρ: density of water
V: velocity of water
μ: dynamic viscosity of water
F_n: Froude Number
σ: surface tension of water.
q: discharge of the fluid per unit width

6. References

[1] Abd el- Aal G. M., Sobeah M., Helal E., El-Fooly M., "Improving energy dissipation on

stepped spillways using breakers" Ain Shams Engineering Journal, 2018, Vol. 9, No. 4, PP. 1887-1896.

[2] Al Saadi A. K., "Study Coefficient of Discharge for a Combined Free Flow over Weir and under Gate for Multi Cases", Euphrates Journal of Agriculture Science, 2013 ,Vol.5, No.4,PP. 26-35.

[3] Al Sayed I. D., Lamia M. and Ibrahim M.M., "Hydraulics of combined triangular sharp crested weir with inverted V-shaped gate", Alexandria Engineering Journal, 2022, Vol.61, No.10, PP. 8249-8262.

[4] Aydin I., Sakarya A.B., Ger A.M. ,"Performance of slit weir"; Journal of Hydraulics Engineering, ASCE, 2006, Vol. 132, No.9, PP. 987–989.

[5] Bshkoj S. Hussein, Shaker A. Jalil, "Hydraulic Performance for Combined Weir-Gate Structure ", Tikrit Journal of Engineering Sciences, 2020, Vol.27 No.1, PP. 40-50.

[6] Elsayed H., Helal E., El-Enany M., Sobeih M., "Impacts of multi-gate regulator operation schemes on local scour downstream", ISH Journal of Hydraulic Engineering , 2021,Vol. 27 , No.1, PP.51-64.

[7] Fadhel A. H., Saleh I. K., Hassan A. O., "Determining the Coefficient of Discharge due to Flow over Composite Weir and below Gates",2015, doi:10.13140/RG.2.2.33844.86406.

[8] Falvey, H., Hydraulic Design of Labyrinth Weirs; American Society of Civil Engineers: Reston, VA, USA. 2003.

[9] Hayawi H. A., Hayawi G. A. and Amal A. G., "Coefficient Of Discharge For A Combined Hydraulic Measuring Device", Al-Rafidain Engineering, 2009, Vol.17, No.6.

[10] Helal E., Abdelhaleem F. S., Elshenawy W.A., "Numerical assessment of the performance of bed water jets in submerged hydraulic jumps", Journal of Irrigation and Drainage Engineering, 2020, Vol.146 , No.7. 04020014.

[11] Kindsvater C.E., Carter R.W., "Discharge characteristics of rectangular thin plate weirs", Journal of Hydraulic Divison, ASCE, 1957, Vol. 83, No.6, PP.1–36.

[12] Negm A. M, Al-Brahim, A.M. and Alhamid, A.A, "Combined free flow over weirs and below gates", Journal of Hydraulic Research, 2002, Vol.40, No.3, PP. 359-365.

[13] Shaker A. J. and Sarhan A. S., "Analysis of Simulation Outputs for the Mutual Effect of Flow in Weir and Gate System", Journal of University of Babylon for Engineering Sciences, 2018, Vol. 26, No. 6, PP. 48-59.

[14] Shaymaa A. M. Al-Hashimi, Huda M. Madhloom, Thameen N. Nahi, Nadhir Al-Ansari , "Channel Slope Effect on Energy Dissipation of Flow over Broad Crested Weirs", Scientific Research Publishing, 2016, Vol.8 , PP.837-851.

[15] Swamee P.K., "Discharge equations for rectangular sharp crested weirs", Journal of Hydraulic Eng. 1988, Vol. 114, No.8, PP.1082–1087.

[16] Tanimu B., Abdullah B., Muhammad M. and Wada. A., "Experimental Study of Flow through Trapezoidal Weir Controlled under A semicircular Gate", FUDMA Journal of Sciences (FJS), 2021, Vol. 5, No.2, PP. 145 – 164.

[17] Zong-Fu Fu, Zhen Cui, Wen-Hong Dai, and Yue-Jun Chen , "Discharge Coefficient of Combined Orifice-Weir Flow", Water, 2018 ; doi:10.3390/w10060699