

Study The Free Flow Over Compound Weir and Below Semi Circular Gate

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Abstract— In order to minimize the sedimentations , depositions and floating materials problems , weirs and gates can be combined together in one device , so that water could pass over the weir and below the gate simultaneously. The aim of this study is to investigate the coefficient of discharge for combined hydraulic measuring device consists of compound weir (have two rectangular notches with trapezoidal notch between them) and semi circular sluice gate , for this purpose fifteen models were constructed and manufactured of Plexiglas sheet of 3 mm thickness with beveled edges to 2 mm thickness. The results show that (C_d) increases as the hydraulic parameters (H/D , H_1/D , H_2/D , H_3/D) increases , and (C_d) values increases as (W) increasing at constant (X) , also the (C_d) values decreasing at increasing the values of (Z & Y). The values of (C_d) range from (0.427 to 0.543) with an average value of (0.485). Semi empirical discharge formula was developed and the predictions from this formula agreed well with the experimental data.

Index Terms— Combined device, compound weir, discharge coefficient, gate.

1 INTRODUCTION

The most common and important water measurement structures that used for controlling, adjusting the flow in irrigation channel and diverting the flow from a main channel to a secondary channel are weirs and gates. When the weirs and gates combined together in one device, new hydraulic condition will be found that is different with weir condition solely or when there is only gate. The combined device will function similar to weirs or gates as a control and discharge measurement device, it will minimize deposition of debris upstream of weirs and minimum maintenance is needed as most of the floating materials and sediments will pass through this device. Comprehensive review of studies dealing the simultaneous flow over weirs and below gates can be found in (Escade 1938), (Charles 1956) and (Chow 1959) as reported in [1]. El-Saiad et al. (1995) investigated the effect of the notch angle of a triangular opening when it is used above and below the rectangular opening, they found that a triangular above a rectangular opening is more efficient than reversed. In (1997), Al-Hamid et al. [2] discussed the effect of hydraulic and geometrical parameters on the combined discharge and presented discharge equations for triangular weirs above rectangular contracted gates, and contracted rectangular weirs above triangular gates. They proved that the prediction of the combined discharge through the use of common discharge coefficients produces significant errors.

Ferro (2000) reported the results of an investigation carried out to establish the stage – discharge relationship for a flow simultaneously discharging over and under a sluice or broad crested gate [3].

The characteristics of the combined flow over the sharp – edged rectangular weir and below the sharp – edged rectangular gate with contractions was studied by [4], they introduced a general dimensionless relationship for predicting the discharge of the combined device.

Recently, Hayawi et al. (2009) [5] investigated experimentally the free flow through a combined hydraulic measuring device consists of rectangular weir over a semi circular gate and proposed a model for predicting the discharge coefficient through it.

Mahboubeh et al. (2011) [6] studied the effect of contraction on scouring in downstream of combined flow over weirs and below gates and various relationships characterizing the scour hole are found on the basis of experimental results.

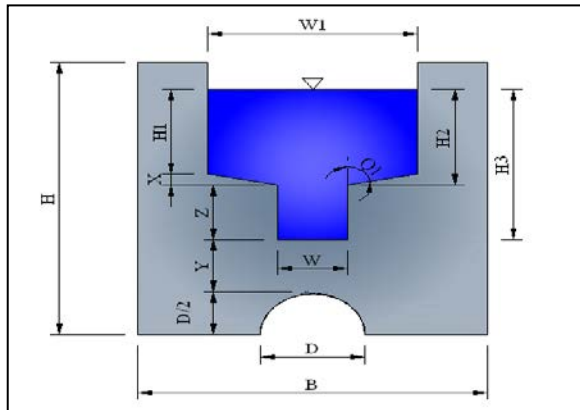
Ismail (2012) [7] investigated the characteristics of the combined flow over sharp crested trapezoidal weir and below rectangular sluice gate and studied the effect of the hydraulic and geometrical parameters on the coefficient of discharge and introduced two equations to evaluate it .

In this paper , the characteristics of the proposed device (compound weir have two rectangular notches with trapezoidal notch between them and semi circular sluice gate) was studied experimentally for different geometrical combinations to the weir and a generalized equation from the experimental investigations was obtained , this equation include all the important variables .

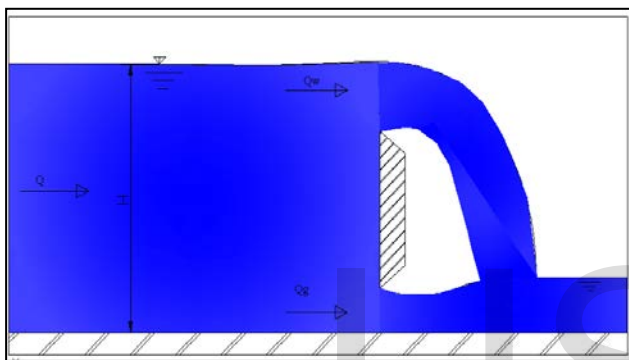
2 THEORETICAL ANALYSIS

The combined free flow over a sharp crested compound weir and beneath a semi circular gate is sketched in Fig. 1.

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a- Cross Section



b- Longitudinal Section

Fig. 1. Definition Sketch For the Combined Hydraulic Measuring Device

The theoretical flow equation for sharp crested compound weir consist of two notches and trapezoidal notch between them can be written as follows :

$$Q_{wtheo} = \frac{2}{3} (2g)^{1/2} W (H_3^{3/2} - H_2^{3/2}) + \frac{2}{3} (2g)^{1/2} W_1 H_1^{3/2} + \frac{2}{3} (2g)^{1/2} W (H_2^{3/2} - H_1^{3/2}) + (8/15) (2g)^{1/2} \tan\theta_1 (H_2^{5/2} - H_1^{5/2}) \quad (1)$$

Where :

Q_{wtheo} : theoretical discharge over the compound weir .

H : total head .

H_1, H_2, H_3 : height of water above the first , second and third notches of the compound weir .

W_1 : width of first notch of the compound weir .

W : width of second and third notch of the compound weir .

g : the gravitational acceleration .

Q_1 : the angle of the crest of the compound weir .

The theoretical flow passes through the semi circular gate can be written as follows :

$$Q_{gtheo} = \frac{1}{8} \pi D^2 (2gH)^{1/2} \quad (2)$$

Where :

Q_{gtheo} : theoretical discharge through the gate .

D : the diameter of the gate opening .

Combining the two equations 1 & 2 , the total theoretical discharge :

$$Q_{theo} = Q_{wtheo} + Q_{gtheo}$$

(3)

To predict the actual total discharge :

$$Q_{act} = C_d \times Q_{theo}$$

(4)

$$Q_{act} = C_d \times \left[\frac{2}{3} (2g)^{1/2} W (H_3^{3/2} - H_2^{3/2}) + \frac{2}{3} (2g)^{1/2} W_1 H_1^{3/2} + \frac{2}{3} (2g)^{1/2} W (H_2^{3/2} - H_1^{3/2}) + (8/15) (2g)^{1/2} \tan\theta_1 (H_2^{5/2} - H_1^{5/2}) + \frac{1}{8} \pi D^2 (2gH)^{1/2} \right] \quad (5)$$

Where :

Q_{act} : free combined actual discharge .

Q_{theo} : free combined theoretical discharge .

C_d : coefficient of discharge for the combined device .

The discharge (Q_{act}) can be written in functional form by utilizing dimensional analysis :

$$Q_{act} = f(H, H_1, H_2, H_3, Z, Y, D, B, W_1, W, X, S, \rho, \mu, \sigma) \quad (6)$$

(6)

Where :

Z : height of the second notch of the compound weir .

Y : the distance between the lower edge of weir crest and the gate top .

B : width of the flume .

X : height of the crest .

S : slope of bed flume .

ρ : density of the water .

μ : dynamic viscosity .

σ : surface tension .

Based on equation (6) and by using Buckingham π - theorem , the following function obtains :

$$Q_{act} / g^{1/2} H^{2.5} = f(H/D, H_1/D, H_2/D, H_3/D, Z/D, W/B, Y/D, R_e, W_e) \quad (7)$$

(7)

The effect of Reynolds number and Weber number is assumed to be negligible for the combined device at high discharges .

3 EXPERIMENTAL SET- UP

Experiments on the combined device were conducted in a glass fiber molded in stainless steel stiffeners sided flume of 18.6 m length with cross section (0.5 m wide by 0.5 m depth) and the bed of the flume made of stainless steel plates.

The water depths were measured by point gages (± 0.1 mm accuracy) mounted on two carriages that can move to any position above the working section (15 m).

The actual discharge entering the combined device was measured by a pre calibrated V-notch weir installed at the outlet of the inlet tank.

A centrifugal pump is used to supply water from reservoir under the ground to the flume inlet tank for recirculation.

A tail gate was mounted at the end of the flume to adjust flow depths . Fig. 2. shows the flume that used to conduct the experiments .

All the experiments were conducted in the Hydraulic Laboratory of Al Najaf Technical Institute - Civil Techniques Department.

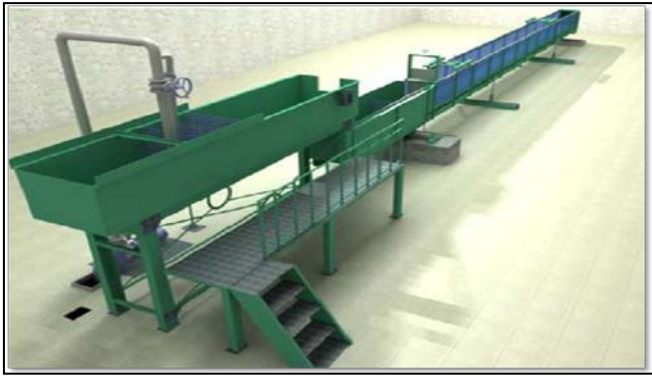


Fig. 2. The laboratory flume

Fifteen combined device models were tested. Table 1 gives the range of various parameters covered in the present study. The models were made of 3 mm Plexiglas sheet with all edges beveled to 2 mm thickness. The models were fixed to the flume at the middle using support from downstream side having the same shape of the model but with large dimensions and made from stainless steel plate (10 mm thick) stuck to the flume side walls using silicon rubber.

TABLE 1
 Details of Tested Combined Devices

Model no.	W_1 cm	W cm	Y cm	Z cm	D cm	$D/2$ cm	X cm
1	18	6	6	6	13	6.5	1
2	18	6	9	6	13	6.5	1
3	18	6	11	6	13	6.5	1
4	18	6	6	9	13	6.5	1
5	18	6	9	9	13	6.5	1
6	18	6	11	9	13	6.5	1
7	18	6	6	11	13	6.5	1
8	18	6	9	11	13	6.5	1
9	18	6	11	11	13	6.5	1
10	18	9	9	6	13	6.5	1
11	18	9	9	9	13	6.5	1
12	18	9	9	11	13	6.5	1
13	18	11	9	6	13	6.5	1
14	18	11	9	9	13	6.5	1
15	18	11	9	11	13	6.5	1

4 ANALYSIS OF RESULTS

4.1 Variation of C_d with the hydraulic parameters

The effect of the hydraulic parameters (H/D , H_1/D , H_2/D , H_3/D) on the C_d are shown in figures 3, 4, 5, 6. From these figures, it can be concluded that the values of coefficient of discharge C_d (which can be obtained from equation 4) increases as the hydraulic parameters increase at constant values for (Z/D , W/B & Y/D).

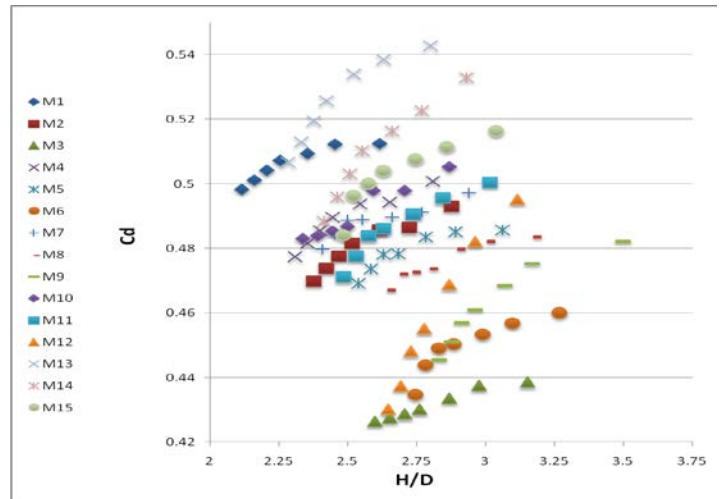


Fig. 3. The effect of (H/D) on C_d

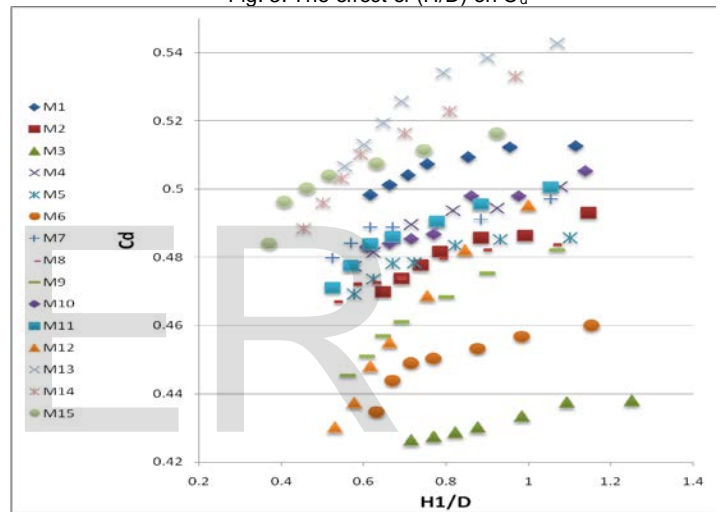


Fig. 4. The effect of (H_1/D) on C_d

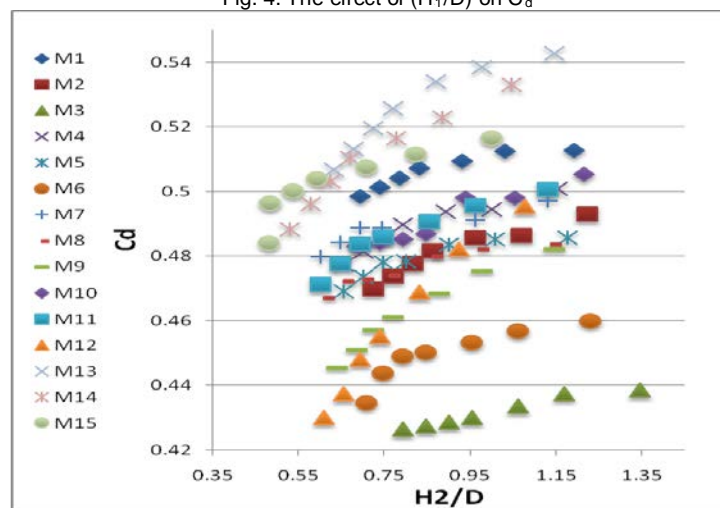


Fig. 5. The effect of (H_2/D) on C_d

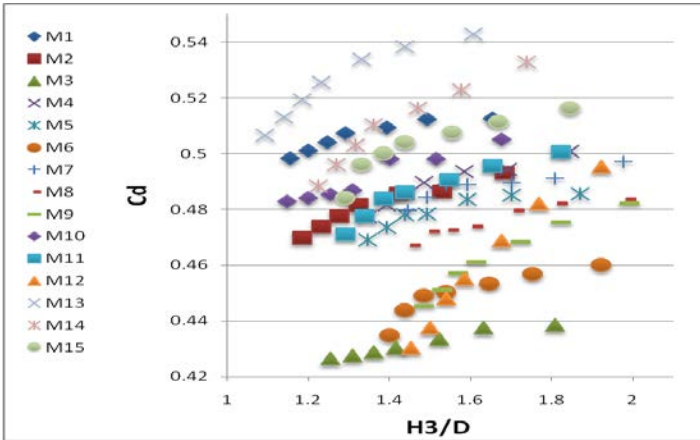


Fig. 6. The effect of (H_3/D) on C_d

4.2 Variation of C_d with Z/D

The influence of the third notch height (Z) on the C_d value has been investigated by using three different heights for (Z) (6 , 9 , 11) cm for specific distance between the lower edge of weir crest and the gate top (Y) as shown in figures 7 & 8. From the figures, it is clear that when the value of (Z) increases then the value of C_d decreases.

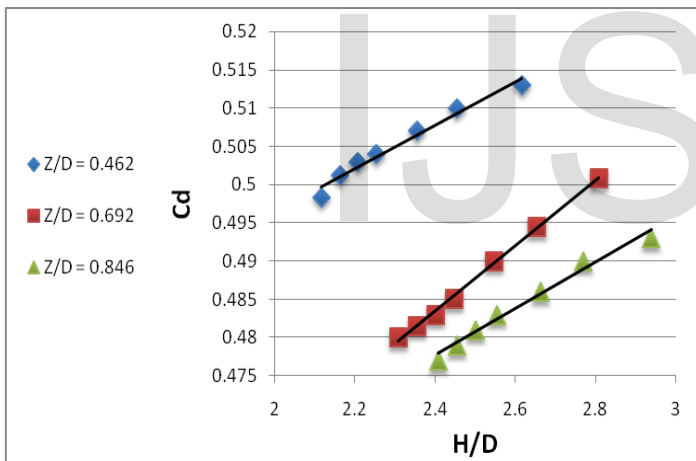


Fig 7. The effect of (Z) on C_d with $Y/D=0.462$

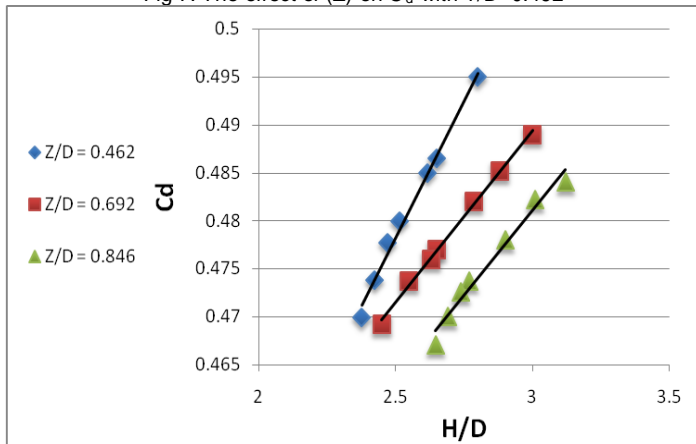


Fig. 8. The effect of (Z) on C_d with $Y/D=0.692$

4.3 Variation of C_d with W/B

The influence of the third notch width (W) on the C_d value has been studied by using three different widths for (W) (6 , 9 , 11) cm for constant crest height ($X=1$ cm) as shown in Fig. 9. , this figure clarify that for constant value of (X) and with increasing the value of (W) then the value of C_d also increases.

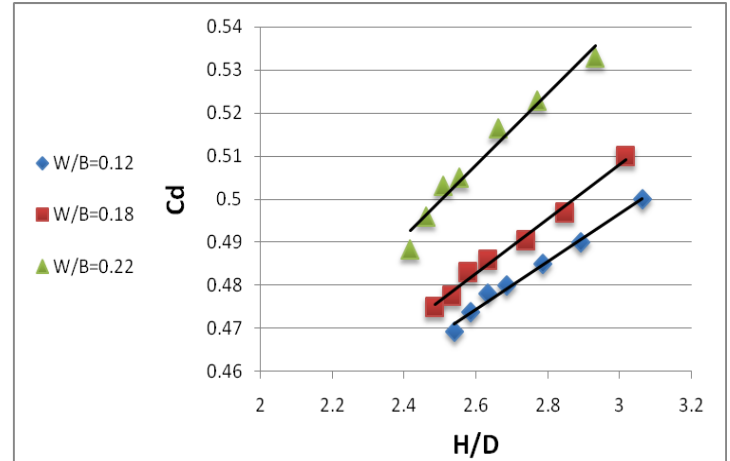


Fig. 9. The effect of (W) on C_d with constant value of $X=1$ cm

4.4 Variation of C_d with Y/D

The distance (Y) has been studied by using nine models and change the value of (Y) three times (6 , 9 , 11) cm for different values for (Z) (6 , 9 , 11) cm and the other geometric parameters are kept constant. Figures 10 , 11 , 12 show that for the same value of (Z) and increasing the value of (Y) causes decreasing in the value of C_d .

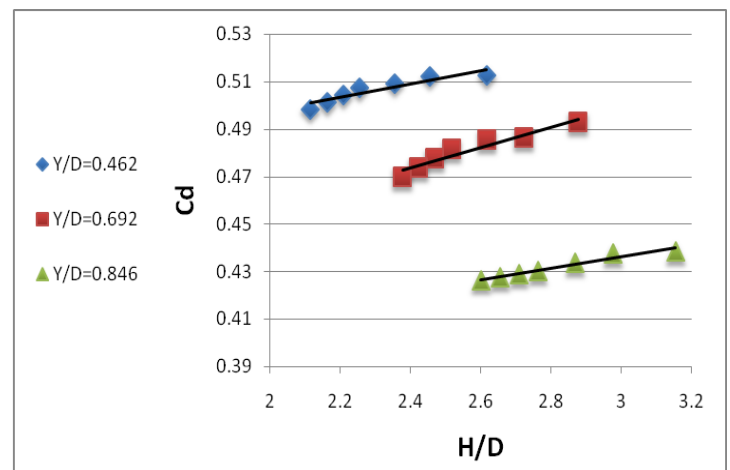


Fig. 10. The effect of (Y) on C_d with $Z/D=0.462$

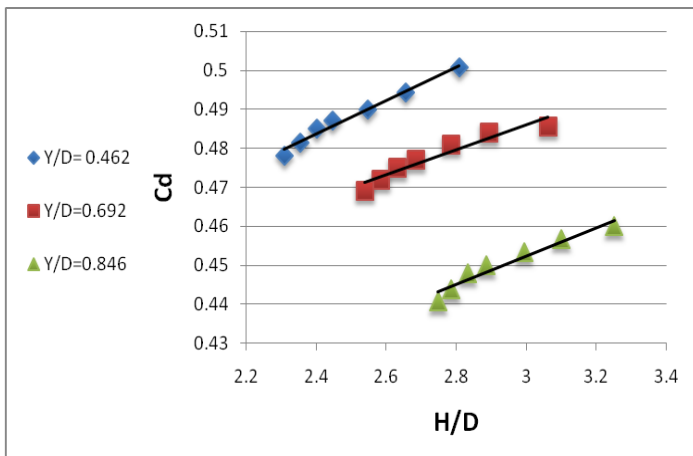


Fig. 11. The effect of (Y) on C_d with $Z/D=0.692$

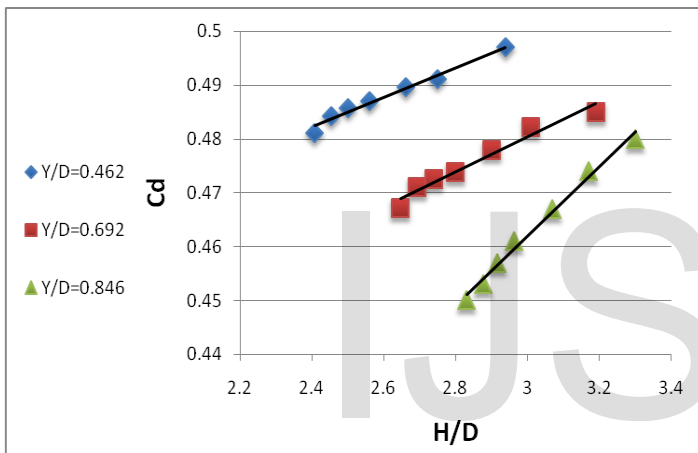


Fig. 12. The effect of (Y) on C_d with $Z/D=0.846$

4.5 Development a new formula

A general non dimensional equation for predicting the coefficient of discharge for the combined device can therefore be written as :

$$C_d = C_1*(H/D) + C_2*(H_1/D) + C_3*(H_2/D) + C_4*(H_3/D) + C_5*(Z/D) + C_6*(W/B) + C_7*(Y/D) \quad (8)$$

By using the computer package (STATISTICA) (multiple linear regression), the values of the constants C_1 to C_7 are found:

$$C_1 = 1.104 \quad C_2 = 0.946 \quad C_3 = -2.002 \quad C_4 = -0.006 \\ C_5 = -1.11 \quad C_6 = 0.414 \quad C_7 = -1.23$$

Then equation (8) become :

$$C_d = 1.104*(H/D) + 0.946*(H_1/D) - 2.002*(H_2/D) - 0.006*(H_3/D) - 1.11*(Z/D) + 0.414*(W/B) - 1.23*(Y/D) \quad (9) \\ R^2 = 0.84$$

Where : R^2 : the coefficient of determination.

4.6

Variation of experimentally observed values of C_d and predicted values by equation 9 is shown in Fig. 13. , which shows

a good agreement.

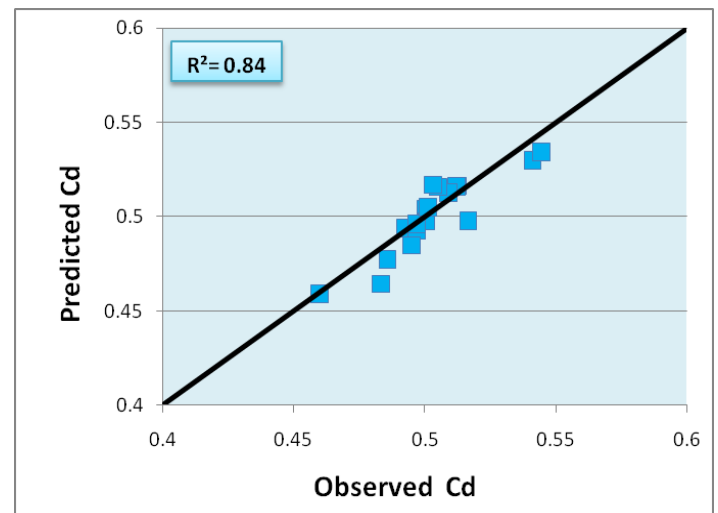


Fig. 13. Relationship between calculated and observed values of C_d

5 CONCLUSIONS

Under the limitations imposed in this study , the following main conclusions are concluded :

- 1- The coefficient of discharge C_d increase as the hydraulic parameters (H/D , H_1/D , H_2/D , H_3/D) increase, and the values of C_d range from (0.543 to 0.427) with an average value (0.485).
- 2- At increasing (Z) for the same distance between the lower edge of weir crest and the gate top (Y) , then the coefficient of discharge decreasing.
- 3- As the width of the third notch of the compound weir (W) increasing for constant value of crest height (X) , then the coefficient of discharge also increasing.
- 4- The coefficient of discharge decreasing with increasing the distance between the lower edge of weir crest and gate top (Y).
- 5- A multi regression analysis were applied to estimate the coefficient of discharge C_d in relationship including the parameters (H/D , H_1/D , H_2/D , H_3/D , Z/D , W/B , Y/D) and agreed well with the experimental data.

6 NOTATIONS

B : Width of the flume (L) .

C_d : Coefficient of discharge (-) .

D : The diameter of the gate opening (L) .

g : The gravitational acceleration (LT^{-2}) .

H : Total head (L) .

H_1, H_2, H_3 : height of water above the first , second and third notches of the compound weir (L) .

Q_1 : The angle of the crest (-) .

Q_{act} : free combined actual discharge (L^3T^{-1}) .

Q_{gtheo} : Theoretical discharge through the gate (L^3T^{-1}) .

Q_{theo} : free combined theoretical discharge (L^3T^{-1}) .

Q_{wtheo} : Theoretical discharge over the compound weir (L^3T^{-1}) .

Re : Reynolds's number (-) .
S : Slope of bed flume (-) .
W : Width of the second and the third step of the compound weir (L) .
W₁ : Width of the first step of the compound weir (L) .
We : Weber number (-) .
X : Height of the crest (L) .
Y : The distance between the lower edge of weir crest and the gate top (L) .
Z : Height of the second step of the compound weir (L) .
 μ : Dynamic viscosity (ML⁻¹T⁻¹) .
 ρ : Density of the water (ML⁻³) .
 σ : Surface tension (MT⁻²) .

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