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Influence of Inclined Bed Channel on Characteristic of Flow for Step Broad–Crested Weirs

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Abstract: Influence of inclined bed channel on characteristic of flow for step broad–crested weirs was investigated experimentally. Discharge coefficient, water surface profile and Froude number were calculated experimentally.The results showed that water surface profiles were smooth and continues having a descending trend from the point of measurement taking the shape of the weir with a steep drop near the downstream face of the weir. Increasing effective head to crest height ratio (H_e/Y) and channel bed slope (S_o), increased the coefficient of discharge (C_D) up to 5%. Also it was found. that for small values of (Fr_2), the weir performance tends to the ideal .and with increase (Fr_2), the discharge coefficient (C_D) decrease for all weir models, because the discharge and the velocity heads increases. Empirical equation was developed on the basis of obtained results.

Keywords: Inclined bed channel, Step broad–crested weirs, Discharge coefficient

Introduction

The weir is an obstruction constructed across a river or stream in order to increase and control water head at the upstream of the weir or for water flow measurement. Weirs with different types considered as the most hydraulic structures which used in open channel flow. The authors [1] are studying the characteristics of square-edge and round-nosed, rectangular broad crested weir under free flow and submerged flow conditions and they found to be a function of the head of water at the upstream causing flow and the radius, of the upstream top corner. While others presented a method for predicting both subcritical and supercritical flow characteristics over drops and describe an empirical relation to roughly calculate the relative energy loss [2]. The Coefficients of Discharge calculated over a large broad – crested weir, two empirical equations were found depending on the geometry of the weir [3]. The single step broad crested weirs are more efficient than traditional weir and the maximum energy dissipation ratio in single step broad crested weirs was approximately (10%) higher than traditional weirs [4].Square edge broad crested weir can be well improved and the discharge coefficient is increased by introducing an upstream face slope of 0.5H: 1V and this value of Slope are quite enough to give high values of discharge coefficient [5]. Hussein et al. [6] have been improved the coefficient of discharge in comparison with traditional weir due to adding a step to the broad crested weir. [7] and [8] giving design tables for a wide range of variables. Hussein et al. [9] studied the hydraulic efficiency of single step broad-crested weir was improved. Empirical equations for energy dissipation and discharge coefficient due to the effecting parameters were derived.

- Selection and peer-review under responsibility of the Organizing Committee of the Conference

the main objective of research is to study the effect of channel slope on characteristics of flow for single step broad – crested weirs.

Experimental Setup

The experiments were achieving in channel is 12 m long, 0.5m width and 0.45 m depth as. The channel was pivoted with jacking station for normal inclination. Triangular sharp-crested weir installed in the inlet of the channel for measuring discharge as illustrated in figure 1. The flume was provided with point gauge installed on the rails to measure water surface.

Figure 1. Channel setup

Weir Models

Five weir models were manufactured and tested in which the downstream crest height and angle channel slope were varied . These models can be classified in to four groups based on the variation of channel slope (S_o) [group (1,2,3 and 4) (S_o = 0 , 0.001, 0.002 and 0.004)] . Each group included the testing of five models based on the variation of D/S weir height (Y_1) [model No.(1,2,3,4 and 5)(Y_1=(12,10,8,6 and 4 cm)]. Details of the testing are shown in table (1) and Fig. (1) . All models were manufactured from thermos stone and well varnished to represent smooth surfaces . To ensure stability of water surface levels and uniform flow with very low turbulence, every model was placed on the bed of the laboratory flume at distance 3.5 m downstream from the flume inlet . Then the model was glued to the flume bed using an adhesive material applied to the boundary of the weir model to resist the overflowing water pressure and to prevent any possible leakage through the sides and bottom of the weir . After construction the testing program started by flowing different discharges to overtop the weir model. for each discharge , upstream water surface profile measurement were recorded by measuring the heads overall the grid points upstream the weir model . All measurements were conducted at the center line of the channel width. In each test, The measurements along the weir models were conducted under the free flow conditions. In all tests free-falling nappe at D/S step of models were fully aerated to prevent ventilation holes.

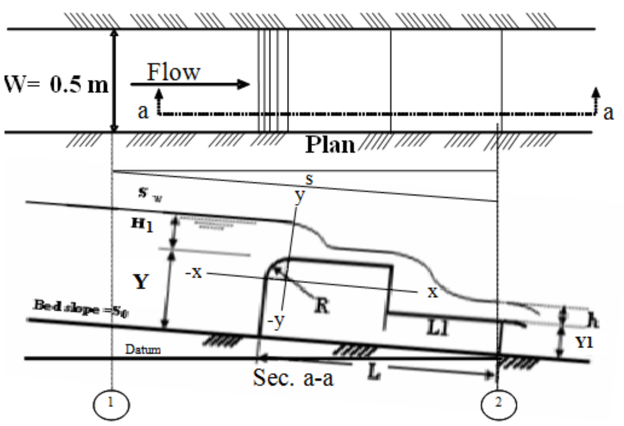

Figure 2. Locations of grid points for the water head measurements

Table 1. Details of the tested weir models

Model No.	Y/Y_1	Slope	Run No.	He(cm)	Discharge Range (Q L/sec)	Range of C_D	Fr_2
1	1	0	1 - 6	- 6.81 11.34	5.43 – 11.9	0.896 - 0.914	1.05-1.32
		0.001	7-12	5.67-10.81	4.17– 11.174	0.906-0.921	1.08-2.04
		0.002	13-18	5.26-11.36	3.78 – 12.25	0.919 - 0.938	1.06 – 2.13
		0.004	19-24	5.37-11.61	3.97 – 12.88	0.936 - 0.955	1.08- 2.18
2	1.2	0	25 - 30	4.34 -11.57	2.77 – 12.47	0.90 -0.929	1.07-1.56
		0.001	31 - 36	5.57-11.04	4.11 -11.69	0.915 - 0.935	1.21-2.31
		0.002	37 - 42	5.47 - 11.27	4.06 -12.32	0.932 - 0.955	1.06-2.13
		0.004	43 - 48	5.58 - 11.52	4.27 -12.95	0.949 - 0.972	1.08-2.17
3	1.5	0	49 - 54	4.95 - 10.5	3.41 -10.82	0.908 - 0.932	1.3-1.79
		0.001	55 - 60	5.57 -11.47	4.14 -12.47	0.923 - 0.941	1.35 -2.33
		0.002	61 - 66	5.47 - 11.17	4.08 -12.25	0.935 - 0.963	1.18-2.3
		0.004	67 - 72	4.75 -11.61	3.35 -13.20	0.948 - 0.978	1.43-2.91
4	2	0	73 - 78	4.24 - 11.59	2.72 -12.76	0.916 - 0.949	1.15-1.8
		0.001	79 - 84	4.32 – 11.83	2.86 -13.24	0.934 - 0.954	1.31 – 2.76
		0.002	85 - 90	5.78 – 11.17	4.50 -12.35	0.948 -0.97	1.45-2.64
		0.004	91 - 96	5.89 – 11.63	4.75 -13.50	0.974 -.998	1.3 – 2.49
5	3	0	97 - 102	4.85 – 11.37	3.32 -12.32	0.91 -0.943	1.02-1.52
		0.001	103 - 108	5.57 – 10.83	4.17 -11.51	0.93 -0.947	1.32-2.36
		0.002	109 - 114	6.51 – 10.85	5.37 -11.73	0.948 - 0.963	1.38- 2.17
		0.004	115 - 120	5.06 – 10.86	3.73 -11.99	0.961 - 0.983	1.41- 3.24

Water Surface Profiles

The experimental results of measurements of water surface profiles along the center line of the channel show a descending trend from the point of measurement taking the shape of the weir with a steep drop near the downstream face of the weir . Fig. (2,3&4) shows the dimensionless center line water surface profiles of Y/H_e versus X/H_e for all test runs of weir model No.(3)[Y/Y_1=1.5 , S_o =0.001 , 0.002 & 0.004] , where , H_e is the effective upstream head above crest and X is the horizontal distance measured from the upstream of the crest.

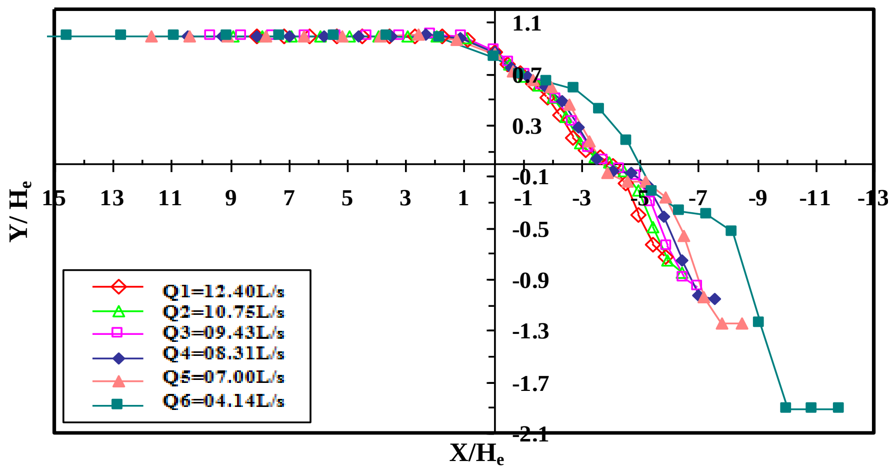

Figure 3. Relation between Y/He versus X/H_e for all runs of weir
(Y/Y_1=1.5 and S_o= 0.001)

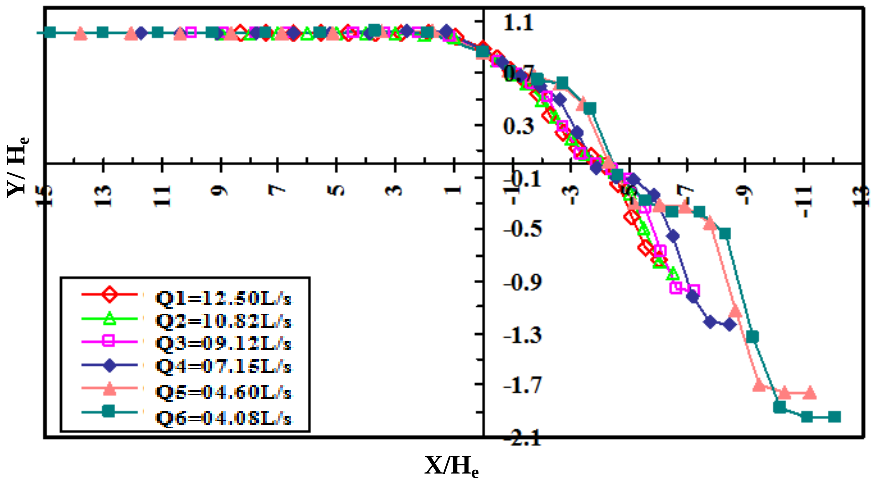

Figure 4. Relation between Y/He versus X/H_e for all runs of weir
(Y/Y_1=1.5 and S_o= 0.002)

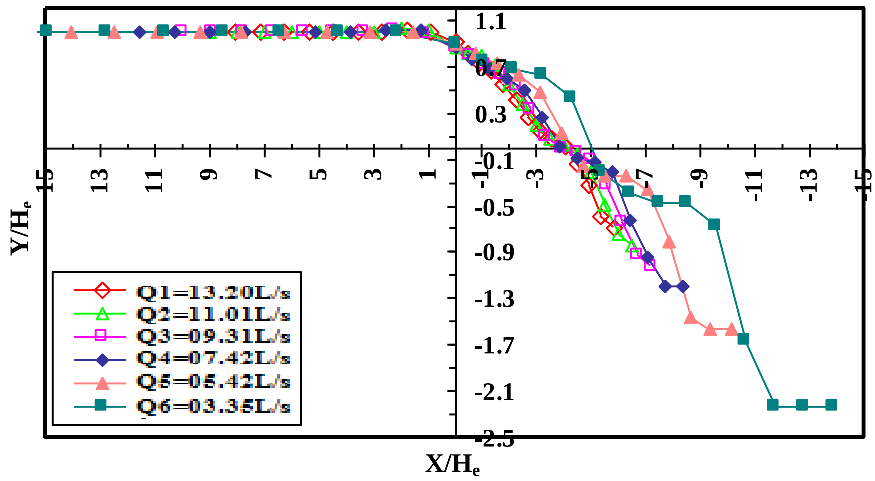

Figure 5. Relation between Y/He versus X/H_e for all runs of weir
(Y/Y_1=1.5 and S_o= 0.004)

The distance upstream crest at which the water surface profile became stable and parallel to the bed of channel for all weir models are shown in table (2) . These are the nearest locations where a point gauge should be located to measure upstream heads accurately.

Table 2. Distance upstream crest at which the water surface profile become stable and parallel to the bed of channel for all weir models

Weir height ratio (Y/Y_1)	**Bed slope of channel S_o=0.001** Distance range	**Bed slope of channel S_o =0.002** Distance range	**Bed slope of channel S_o =0.004** Distance range
1	**(1.9 - 8.19)H**	**(2.73 - 8.2)H**	**(3.8 - 8.56)H**
1.2	**(1.37 - 8.23)H**	**(1.83 - 8.3)H**	**(1.4 - 8.5)H**
1.5	**(1.8 - 7.9)H**	**(2.7 - 8.0)H**	**(2.7 - 8.0)H**
2	**(1.81 - 7.84)H**	**(1.85 - 8.0)H**	**(2.7 - 8.0)H**
3	**(1.9- 8.57)H**	**(2.86 - 8.57)H**	**(3.81 - 8.57)H**

Theoretical Consideration

Dimensional Analysis

The broad crested models are based on the following assumptions: flow upstream of weir is steady, sub-critical and two dimensional; the effect of flow surface tension is eliminated. For rectangular broad crested weir assuming the critical flow on the weir crest [9]:

The relevant parameters in the study of single step broad–crested weirs come from the following groups:

(A)- Fluid properties and physical constants : kinematics viscosity of water $\upsilon(m^2/s)$ and the acceleration of gravity $g(m/s^2)$,
(B)- Channel geometry : the bed slope of channel S_o (dimensionless),
(C)- Weir geometry : radius of the upstream corner of the weir R(cm), upstream weir height Y(cm), downstream weir height Y1(cm), length of weir L(cm), length of d/s stepped weir L1(cm) and width of weir W(cm),

(D)- Upstream flow properties : effective upstream head above crest including approach velocity head He(cm) , flow rate over the weir per unit width q_w (m^2/s).

For a free flow over a single step broad–crested weir with rounded upstream corner, a functional relationship can be taking all the above parameters and written as follows.(see Fig(1)) :

$$\mathbf{f_1(q_W, H_e, Y, Y_1, L, L_1, W, R, \upsilon, g, S_O) = 0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots . \mathbf{(1)}$$

Since, L; L_1, W , and R. are fixed in this study then equation (1) can be rewritten as :-

$$\mathbf{f_2(q_W, H_e, Y, Y_1, \upsilon, g, S_O) = 0} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .. \mathbf{(2)}$$

Using Buckingham Pi-theorem and after certain permissible manipulations, Eq.(2) becomes:

$$\mathbf{C_D = \frac{q_w}{\left(\frac{2}{3}\right)^{3/2} * (g)^{1/2} * (H_e)^{3/2}} = f_3\left(\frac{H_e}{Y}, \frac{Y}{Y_1}, R_e, F_{r2}, S_o\right)} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(3)}$$

$\mathbf{R_e}$ = Reynolds number, and
$\mathbf{Fr_2}$ = Froude number.

Reynolds number will have very large values and hence its effect on C_D will be very little, therefore, R_e can be dropped and Eq.(3) can be rewritten as:

$$C_D = f_4\left(\frac{H_e}{Y}, \frac{Y}{Y_1}, F_{r2}, S_o\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$$

Factors Affecting on the Coefficient of Discharge

Effective Head to Crest Height of weir Ratio (H_e/Y)

a)*When (Y/Y_1) constant:*

The experimental results for all weirs showed that a relation between C_D , and (H_e/Y), for different angles of channel bed slope [S_o = 0 , 0.001, 0.002 & 0.004] were shown in Figs.(5,6,7,8 & 9) , respectively. From these figures one may observe that for the same ratio (Y/Y_1) an increase in He/Y causes an increase in C_D, this could be made the over flowing process becomes easier , smooth and no nappe was visible.and also Fig.(8) show that weirs of upstream to downstream height ratio (Y/Y_1=2 give higher value of C_D =0.985 at H_e/Y=0.7 & S_o = 0.004) than those of [(Y/Y_1=1,1.2,1.5 & 3),(C_D =0.949 ,0.962,0.968 & 0.974)] at the same value of (H_e/Y & S_o) above.

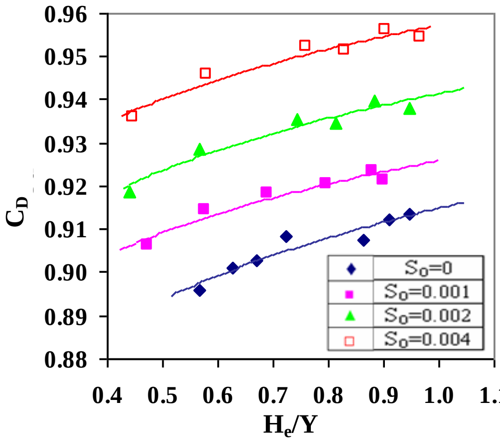

Figure 6. Relation between C_D versus H_e/Y for weirs of (Y/Y_1=1).

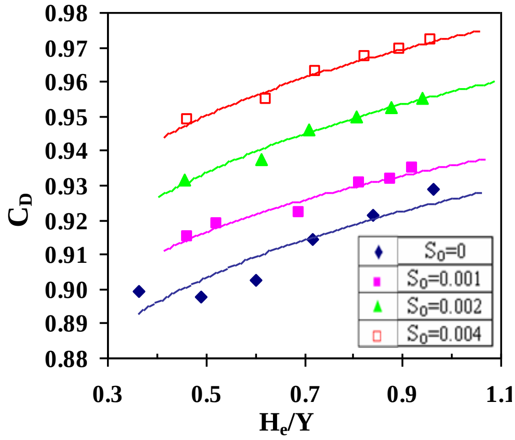

Figure 7. Relation between C_D versus H_e/Y for weirs of (Y/Y_1=3).

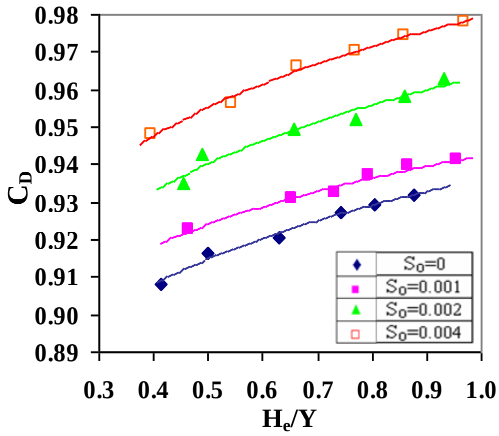

Figure 8. Relation between C_D versus H_e/Y for weirs of (Y/Y_1=1.5).

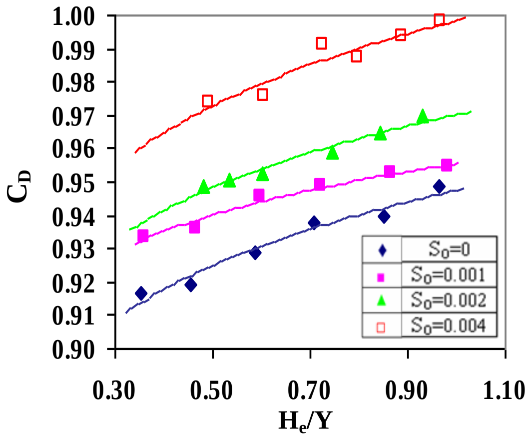

Figure 9. Relation between C_D versus H_e/Y for weirs of (Y/Y_1=2).

b) *Bed slope ofchannel(S_o) constant*

The experimental results for all weirs showed that is a relation between the discharge coefficient (C_D) , and upstream head to crest height of weir ratio (He/Y) . at different upstream height to downstream height of weir ratio [(Y/Y_1=1,1.2,1.5,2 & 3)] are shown in figs.(10,11,12 & 13) , respectively. These figures showed that, an increase in H_e/Y Value causes an increase in C_D value at the same bed slope of channel(S_o). This also could be attributed to reason that as the head above crest increases the over flowing process becomes easier and continues.

From fig.(13) it is interesting to realize that weir on the channel with angle of bed slope[S_o = 0.004 give higher value of C_D =0.99 at He/Y=0.8 & (Y/Y_1=2) than those of weirs (S_o = 0 , 0.001 & 0.002) ,(C_D =0.94 ,0.955 & 0.962)] at the same value of (H_e/Y & Y/Y_1) above.

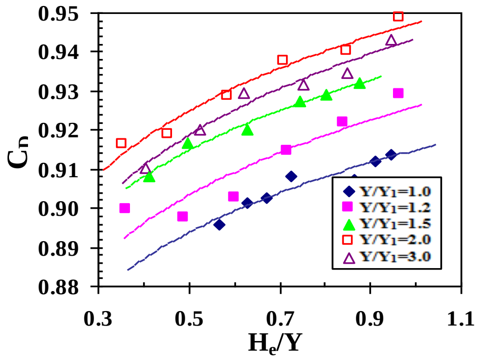

Figure 10. Relation between C_D versus H_e/Y for weirs of (S_o=0).

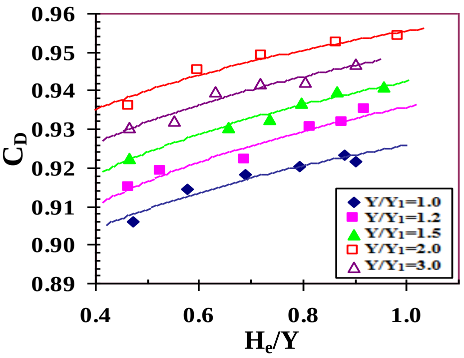

Figure 111 Relation between C_D versus H_e/Y for weirs of (S_o=0.001).

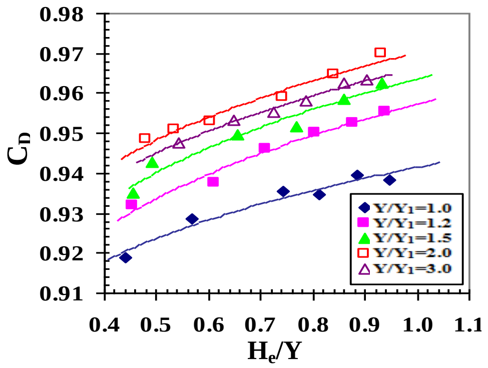

Figure 12. Relation between C_D versus H_e/Y for weirs of (S_o=0.002).

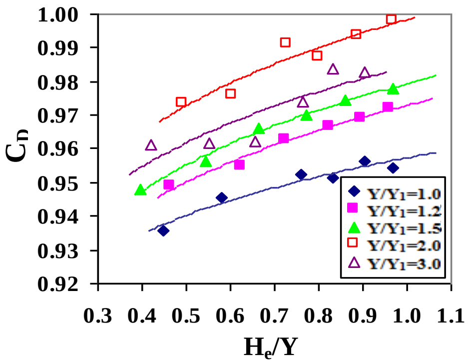

Figure 13. Relation between C_D versus H_e/Y for weirs of (S_o=0.004).

Froude Number (Fr_2)

The relation between discharge coefficient (C_D) and Froude number (Fr2) at downstream for all weir models (Y/Y_1=1,1.2,1.5,2 & 3) , is shown in figs (15,16,17 & 18) , respectively. It is clearly seen that for all small values of (Fr_2) , the weir behaves almost ideally giving high values of (CD) this behavior is explained that for small values of (Fr_2) the weir discharge is small and velocity head of the flow is very small ,and the operating head is the same at every point along the crest being sensibly equal to the head in the approach channel . therefore, for small (Fr_2) values , the weir performance tends to the ideal .and as (Fr_2) increases , the discharge coefficient (CD) decrease , because the discharge and the velocity heads increases; consequently. ,a large proportion of the crest operates under a head less than that in the approach channel with corresponding fall in performance .

From fig. (18) it is seen that weirs of (Y/Y_1=2 and S_o =0.004) give higher values of CD than weirs of [(Y/Y_1=1,1.2,1.5 & 3),(S_o = 0 , 0.001 & 0.002)]due the effect of step**.**

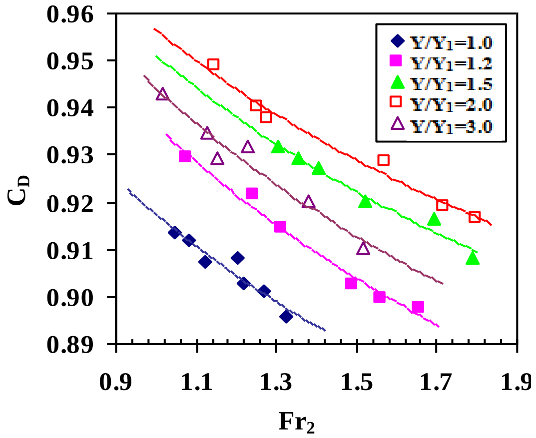

Figure 15. Relation between C_D versus Fr_2 for weirs of (S_o=0).

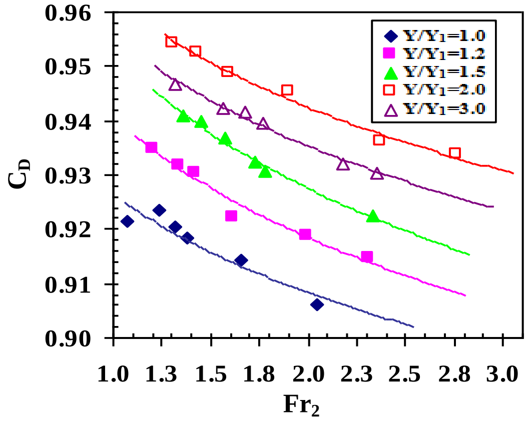

Figure 16. Relation between C_D versus Fr_2 for weirs of (S_o=0.001).

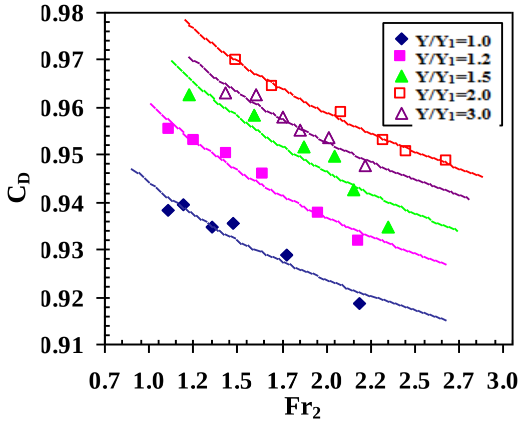

Figure 17. Relation between C_D versus Fr_2 for weirs of (S_o=0.002)

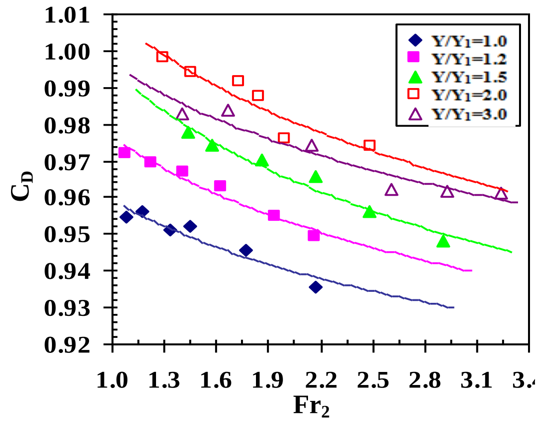

Figure 18. Relation between C_D versus Fr_2 for weirs of (S_o=0.004)

Angle Bed Slope of Channel (S_0)

One of the main objectives of this study is to determine the effect of bed slope of channel S_o on discharge coefficient C_D. Therefore Fig.(14) shows the effects of S_o on C_D for the weir models ratio Y/Y_1=2. and also may observe that C_D increases significantly with the increase of S_o. The variation of average values of C_D with S_o is shown in Fig.(14) indicating that the average value of C_D reaches the highest value when S_o is equal to 0.004 , this means that well the relation between discharge coefficient C_D and angle bed slope of channel S_o is increases linearly.

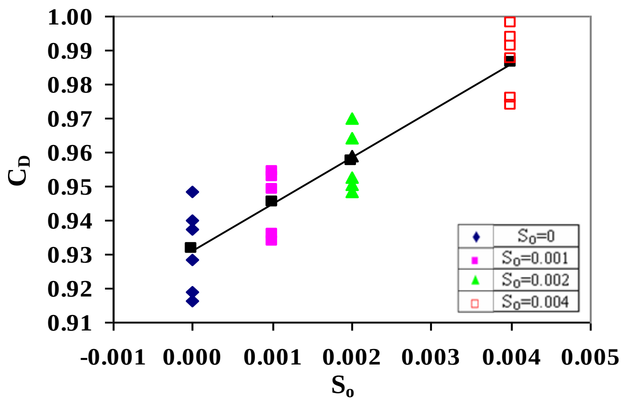

Figure 14. Relation between C_D versus S_0 for weirs of (Y/Y1=2).

Empirical Expressions of Discharge Coefficient

Using (SPSS-20.0) was developed to correlate the coefficient of discharge C_D with a correlation coefficient =0.93. Empirical equation was developed on the basis of obtained results. equ (4)

$$\mathbf{C_D = 0.85 + \left[0.06 * \frac{H_e}{Y}\right] + \left[0.01 * \frac{Y}{Y_1}\right] + [0.008 * F_{r2}] + [10.45 * S_O]} \dots\dots\dots\dots\dots\dots (\mathbf{5})$$

Figure 19 shows the relation between predicted versus observed values of C_D.

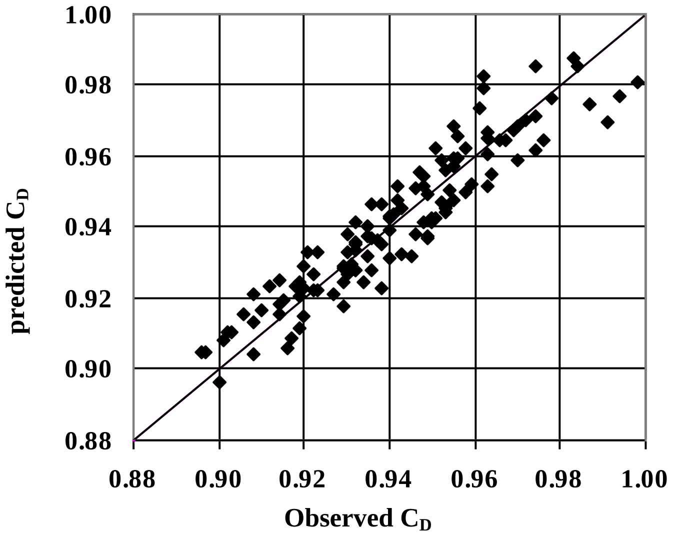

Figure 19. Relation between Predicted C_D versus observed C_D for all weir models.

Conclusions

With in the limits of the experimental data of the present investigation, the following main conclusions can be summarized as:

1-Traditional broad - crested weirs can be well improved when making it as an single step Broad– Crested Weirs. Also The value of (C_D) increases with the increase angle bed slope of channel(S_o) and increase of (Y/Y_1) values reaching its highest value when Y/Y_1 values reach 2.

2-For all weirs model one may observe that at the same ratio of (Y/Y_1)and at the same bed slope of channel(S_o) an increase in He/Y causes an increase in C_D.

3- Weir of ratio(Y/Y_1=2 give higher value of C_D =0.985 at H_e/Y=0.7 & S_o = 0.4) than other weirs, Fig.(8). Also weir with bed slope (S_o = 0.004 give higher value of C_D =0.99 at H_e/Y=0.8 & Y/Y_1=2) than other weirs Fig.(13).

4-For weir model indicated that the average value of C_D reaches the highest value when S_o is equal to 0.004,and also the relation between C_D and S_o is increases linearly. Fig.(14)

5- For all weir models one may observe that when (Fr_2) increases , the discharge coefficient (C_D) decrease.

6- Empirical power expressions were obtained for single step broad–crested weirs to estimate discharge coefficient (C_D) in terms of effective head to crest height ratio (H_e/Y), upstream crest to downstream height ratio($Y//Y_1$), Froude number (Fr_2) at downstream of the weir and bed slope of channel (S_o) with high correlation coefficients=0.933.

Acknowledgements or Notes

The Following Symbols are used in this Paper

C_D =dimensionless weir discharge coefficient ,

f1 to f4 =signify function of ,
g = acceleration due to gravity (m/s^2),
H1 = upstream head above crest(cm),
He = effective upstream head above crest(cm) ,
h = downstream head (cm),
L = weir length (cm),
L1 = length of d/s step weir (cm),
W = width of weir (cm),
Y = upstream weir height (cm),
Y1 = downstream weir height (cm),
q_w = flow rate over the weir per unit width (m^2/s) ,
R = radius of the upstream corner of the weir (cm),
R_e = Reynolds number (dimensionless),
Fr_2 = Froude number (dimensionless) at d/s,
S_o =Bed slope of channel (dimensionless),
υ = kinematics viscosity (m^2/s).

References

Gogus , M. , Defne , Z. and Ozkandemir,V.,(2006). Broad-Crested Weirs with Rectangular Compound Cross Sections. *Journal of Irrigation and Drainage Engineering*, Vol.132, No.3, June, PP.272-280.

Sarker, M .A. and Rhodes, D. G.,(2004). Calculation of Free-Surface Profile over a Rectangular Broad-Crested Weir. *Flow Measurement and Instrumentation*,Vol.15, Issue 4, August, PP.215-219.

Gonzalez, C.A. and Chanson, H.,(2007). Experimental Measurement of Velocity and Pressure Distribution on a Large Broad-Crested Weir. *Flow Measurement and Instrumentation*,Vol.18,Issue 3-4,June-August,PP.107-113.

Noori, B. M. and Juma ,I .A.,(2009). Performance Improvement of Broad Crested Weirs. *Journal of Al-Rafidain Eng.* / Mosul University, vol.17,no.2,pp.95-107.

Al-Talib, A. N. J. (2007). *Laboratory Study of Flow Energy Dissipation Using Stepped Weirs* M. Sc . Thesis. Engineering College, University of Mosul. Iraq.

Hussein H. , Juma I. and Shareef S. (2009). Flow Characteristics and Energy Dissipation Over Single Stepped Broad – Crested Weirs . *Journal Al- Rafidain Engineering*, College of Engineering University of Mosul. Iraq.

Bos, M. G.; Replogle, J. A. and Clemmens , A. J. (1984). *Flow Measuring Flumes for Open Channel Systems*. John Wiley and Sons, Inc., New York, N.Y. .

Boiten , W.,(2002). Flow Measurement Structures. *Flow Measurement and Instrumentation*, Vol.13, Issues 5-6, December, PP. 203-207 .

Hussein, H.H., Juma, I.A.K., Shareef, S.J.S. (2011). Improving the hydraulic performance of single step broad-crested weirs, *Journal of Al-Rafidain Engineering, Mosul University*, 7 (1), 1-12.

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