Head Discharge Relationship of Thin Plated Rectangular Lab Fabricated Sharp Crested Weirs

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ABSTRACT

Measuring open channel flows has been a major challenge at the field level. Because of the fact that the measuring devices are to be made from procedures and materials prescribed in standard codes. Weirs over a period of time had been used to measure discharges in open channel systems. But non-availability of standard material at village level proves to be a major bottleneck in implementing weirs as field measurement devices. The present experimental study is an attempt to prove the good hydraulic performance of weirs made of locally available metal sheets. That use of complicated material and machining is not necessary in the fabrication of rectangular weir. A discharge formula for the rectangular weir of different sizes is extensively studied. From the experimental study it is concluded that the C_d value for each weir is nearly same. Also material and slight variation in thickness has no effect on the C_d value in case of rectangular sharp crested weir.

Keywords: Coefficient of discharge; Head; Hydraulic characteristics; Open channel flow, Weirs.

NOMENCLATURE

b	opening of weir (m)		P	crest height (m)
B	width of rectangular channel (m)		Q	discharge in (m³/s)
C_d	coefficient of discharge		R^2	coefficient of determination
g	acceleration due to gravity (m²/s)		SCW	sharp crested weir
$G. I.$	Galvanized iron		$4H$	upstream distance four times the maximum head over the weir
H	upstream head (m)			
K	coefficient			
$M. S.$	mild steel		ρ	mass density (kg/m³)
n	exponent			

1. INTRODUCTION

In India open channels in irrigation utilities are used for transportation of water for irrigation purpose. Water supplied to the fields by using open channel, implies that discharge measurement becomes necessary, as the losses from infiltration and evaporation need to be evaluated.

For the measurement of discharge the weir is a section having simple rectangular or other shape made by any material. According to Isrealsen and Hansen (1962) a weir is an obstruction at the bottom of a channel which is made to deflect the flow over it. Researchers have made extensive successful experimental studies on rectangular weir and developed various formulations for discharge. A weir having thin edge is known as a sharp crested weir (SCW) whereas, weir with appropriate width is called as broad crested weir.

The details of SCW is shown in Fig. 1. Bos (1989) derived discharge formula for rectangular weir using energy consideration principle.

$$Q = \frac{2}{3} \times C_d \sqrt{2g}\, bh^{3/2} \qquad (1)$$

Where Q is discharge , b is weir width, h is head over the weir, g is acceleration due to gravity and C_d is discharge coefficient. But viscous effect and stream line curvature due to weir contraction are neglected.

Kindsvater and Carter (1959) developed an improved method for computing rate of flow through rectangular, thin-plate weirs. Investigator

also applied this method for fully side suppressed, partially contracted and fully contracted rectangular weirs (USBR Water Measurement Manual). Kulin and Compton (1975) discuss the method and equation for rating fully contracted V-notch weirs with an angle between 25^0 and 100^0. This method also rates partially contracted 90^0, V-notch weirs (USBR Water Measurement Manual).

Ramamurthy *et al*. (1987) had carried out experimental work on two dimensional SCW and generated a general relationship between the weir discharge coefficient (C_d) and the parameter (H/W) (where H is the driving head and W is the weir height) by using momentum principle. Experimental results were correlated with the proposed relationship for the weir discharge coefficient by Ramamurthy *et al*. (1987).

Bagheri and Heidarpour (2012) investigated flow characteristics of rectangular SCW for different heights, width and three dimensional velocity using Acoustic Doppler Velocity meter (ADV). Further they developed an expression for angle of the spilling jet (ψ) by analyzing various velocity profiles and considering various hydraulic parameters such as width and crest of the weir. Aydin *et al*. (2011) considered a rectangular SCW and conducted comprehensive experimental study to investigate the hydraulics of flow over SCW and their experimental study indicates that discharge is independent of weir height and width.

Mitra and Mazumdar (2004) describe the effect of various parameters like viscosity, surface tension, and velocity of approach on the coefficient of discharge examined for the SCW. Investigator stated that the coefficient of discharge (C_d) is very large at low heads for rectangular weir.

In the present experimental study a detailed procedure for carrying out flow studies on the rectangular SCW was followed. The weirs were made by hand, using galvanized iron (G.I.) and mild steel (M.S.) material. Weirs with varied crest height (P) for different b/B ratio were fabricated, where b- width of weir opening (m) B- width of channel (m) P- crest height (m).
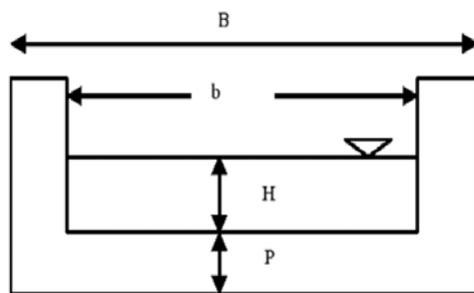
Fig. 1. Front view of rectangular sharp crested weir.

The objectives of the present experimental study are as follows

- To investigate flow characteristics over SCW.

- To test the efficiency of new laboratory fabricated weirs for standard flow condition.

- To study effect of variation of crest height and base width on head over the notch.

2. EXPERIMENTAL SETUP AND METHODOLOGY

The complete work was carried out in the Water Resources Engineering Laboratory of the Civil Engineering Department at Visvesvaraya National Institute of Technology, Nagpur, India. A rectangular flume 4.2 m long and 1.2 m in width, non tilting type was used in the experiment. The experimental setup is a self contained one having circulating arrangement for the water. A 3 HP pump makes the circulating mechanism work efficiently in the flume. The flume is installed with perplex glass sheets as side walls which make the viewing of the experimental run easy. At the entrance into the channel, flow is regulated by converging vertical plates to prevent vortex motion and thus to control the damp fluctuations at the entry of flume. The water after the weir was then collected into a measuring tank with dimension 4m×3m. A calibrated Krohne Marshall make electromagnetic flow meter of 0.1015 m diameter was fitted to the feeding pipe line. Proper care was taken to avoid any electric or magnetic field being formed in the vicinity of this flow meter. A vernier type gauge with accuracy $\pm$ 1mm was used for measuring the bed elevation and water surface elevation. Calibration was done before every run of the experiment to prevent instrumental errors. The depth rod was adjusted accurately to the surface of water to get the value of 'H'. While measuring H it was ensured that the flow in the channel was stable and constant. Discharge is maintained for individual run.

Rectangular weir plates made up of different material like brass, mild steel and galvanized steel were used for experimental study. Out of these weirs especially the brass material weir was made by using ASTM standard and with help of skilled workmanship and used for C_d value calibration. However the weir made of M.S. and G.I. was fabricated at the lab itself using metal cutting scissors. Material chosen for the construction of these weirs was also procured from the local market. Different weir sections were selected having different b/B ratio. The dimension of weir opening (b) was made to 0.2, 0.3 and 0.4 m size. The width of channel (B) is 1.2 m was measured. The crest height (P) is varied as 0.15, 0.2 and 0.25 m. Thus for each crest height there will be three sets of weirs varying the width of opening like 0.2, 0.3, 0.4 m. According to Bos (1989) the minimum weir height (P) was suggested as 10 cm. Aydin et. al. (2011) stated that when the weir height is enough, there are no influences from the channel bed on the flow over the weir, but when $\frac{h}{p}$ ratio is high then considerable influences occurred from the boundary layers on the side walls of the measuring channel.

Table 1 C_d values for different material and location

Sr. No.	Materia	C_d values at4h max.	C_d values at 6h max.	C_d values at 10h max.
1	Brass	0.661291	0.65071	0.62527
2	M. S.	0.66547	0.647237	0.6298
3	G. I.	0.666524	0.647771	0.63112

Table 2 cases of weir having different crest height and width of weir

Crest Height (P) in m	Width of Weir opening (b) in m	Width of channel (B) in m	b/B ratio
0.15	0.2	1.2	0.167
0.2	0.2	1.2	0.167
0.25	0.2	1.2	0.167
0.15	0.3	1.2	0.25
0.2	0.3	1.2	0.25
0.25	0.3	1.2	0.25
0.15	0.4	1.2	0.33
0.2	0.4	1.2	0.33
0.25	0.4	1.2	0.33

Thus it can be inferred that crest or weir height (P) is influencing parameter on which the discharge characteristics are dependent. To find out the effect of crest height on discharge - head relationship the crest height has been increased in the range of 0.15, 0.20 and 0.25 m respectively.

Once the calibration process was completed the accuracy of discharge measurement depend on the measurement of water level (H) on upstream side of the weir. Point gauge with vernier scale having accuracy ± 1mm was used for measurement of this water level. The point gauge was fixed at an upstream distance four times the maximum head over the weir (Bos 1989). Because of bottom boundary effect the nature of flow crossing through the weir section should be free flow condition, therefore weir section is used for discharge measurement and discharge can be determined by measuring head over the weir. The head discharge relationship for P= 0.15, 0.2, and 0.25 m weir heights are shown in Fig. 2.

3. DATA ANALYSIS

The objective of the experimental study was to find out (C_d) for weir which was made of G.I. and M.S. material and compare the variation of Q vs. H. The b/B ratio is varied along with different crest height (P). Head discharge measurements were performed for 09 cases with different b/B ratio and weir height (P) shown in table 2.

3.1 Coefficient of Discharge (C_d)

As it is evident from standard literatures that C_d value is a parameter which mainly governs the weir applicability to various hydraulic situations. After performing experiment the C_d value for three

different types weirs fabricated from different materials was found as,

3.2 Head –Discharge Relationship for Different Weir Heights (P)

From present experimental study it was found that for each material type the C_d value is nearly same. Therefore galvanized steel is selected for performing next experiment because galvanized steel is easily available in market. The geometric parameters of the weir such as height of crest (P) and width of weir (b) were varied and different variation are listed below.

From the Fig. 2 it is evident that for different crest height (P) with b/B ratio = 0.167, 0.25 and 0.33 the head over the notch increase along with the increasing discharge. From Fig. (b) it can be concluded that when b/B ratio increases (b/B=0.25) the head over the notch is just coincided whereas in Fig (a) the graph line for b/B =0.167 are separated. In the same manner when b/B ratio is increased (b/B =0.33) the head over the notch for different crest height (P) is coincided and single linear line with ($R^2 = 0.994$) obtained between different crest heights. The ranges of experimental data are given in Appendix.

3.3 Relationship Between Discharge and C_d

From the Fig. 3 it is very clear that for low discharge the coefficient of discharge (C_d) is high but when discharge is increased the C_d value decreases. After some discharge value the C_d value for different crest height and also different b/B ratio coincide in same line. But when discharge is 0.002 to 0.004 m³/s the C_d value for each weir section is

different, even when the discharge increases up to 0.011 the C_d value for each weir section correlate strongly.

(a)

(b)

(c)
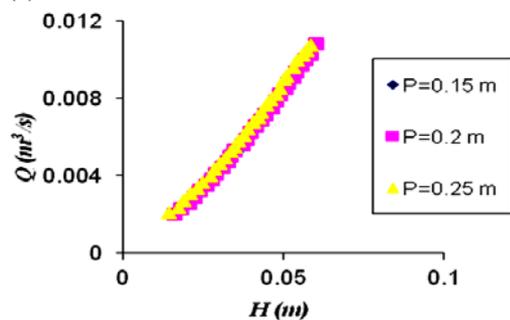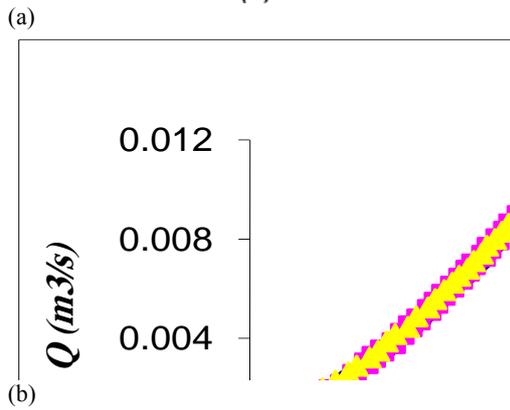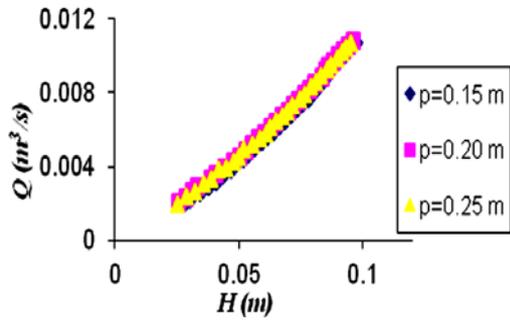
Fig. 2. Head - discharge relationship for various weir heights (a) b = 0.2 m (b) b = 0.3 m (c) b = 0.4 m.

3.4 Dimensional Analysis

In order to determine stage discharge relationship for rectangular weir a non dimensional relationship was developed. The discharge passing through rectangular weir is a function of upstream head and dimensions of rectangular weir under free flow condition.

$$f(Q, H, P, B, b, g, \rho) = 0 \qquad (2)$$

Where, Q = Discharge, H = upstream head, B = width of rectangular channel, g = acceleration due to gravity, P = crest height, b = opening of weir ρ = mass density

All these non dimensional parameters are grouped together to form different dimensionless parameters by chosing group of different parameters. By applying the concept of Buckingham π theorem for dimensionless analysis the dimensionless discharge

is

$$\frac{Q \times B^{1/3}}{b \times g^{4/3}} = K \times \left(\frac{H}{B}\right)^n \qquad (3)$$

Where K is coefficient and n is exponent
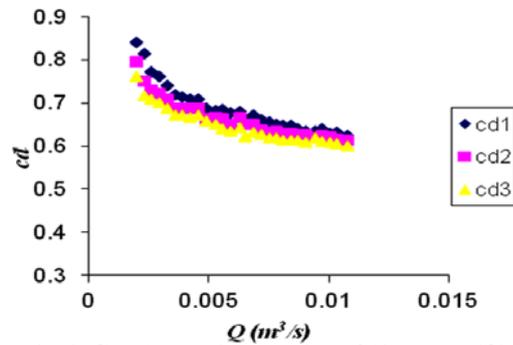
Fig. 3. Graph showing relation of discharge (Q) Vs. coefficient of discharge (c_d).
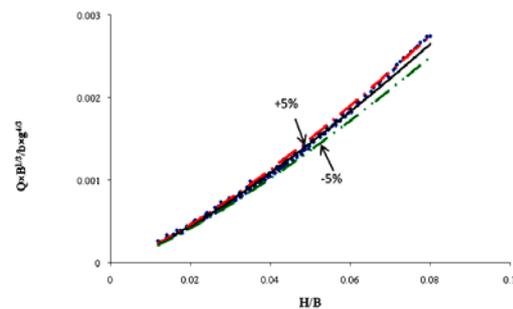
Fig. 4. Relation between Dimensionless discharge (m^3/s) Vs. Dimensionless head (m).

Considering the fact that there can be a relation between discharge and head. All the data of observations are combined and regression analysis was done for all the recorded observations. Based on the regression analsis the following relationship is obtained $Q = 0.067 \times \left(\frac{H}{B}\right)^{1.283}$ with coefficient of determination (R^2) =0.995. Error curves with +5% and -5% plotted by regression. Interestingly all the observations lie within limit +5% and -5%.

4. RESULT AND DISCUSSION

An Experimental study was conducted for measuring the different flow characteristics of rectangular SCW. Experimental runs were conducted on various b/B ratios of 0.167, 0.25 and 0.33 with different P values of 0.15 cm, 0.2, cm and 0.25 cm respectively. Also, three different materials brass, galvanized iron and Mild Steel were used for the fabrication of SCW. All the data of observation sets was combined and regression analysis was done for all recorded observations. Based on the regression analysis the following relationship is obtained as $Q = 0.067 \times \left(\frac{H}{B}\right)^{1.283}$ with coefficient

of determination as $(R^2) = 0.995$. Two curves with errors +5% and -5% plotted around the curve of regression analysis. It can be seen that all the observations lie within limit +5% and -5%.

5. CONCLUSION

Based on the observations carried on discharge measurement by rectangular SCW the following conclusions are drawn:

- Head-Discharge relationship for SCW is found to be a exponential series.
- It can be concluded that as the b/B ratio increases, the head over the notch decreases for the same discharge value.
- The crest height P has negligible effect on the discharge characteristics of SCW.
- The discharge in SCW can be expressed as,

$$Q = 0.067 \times \left(\frac{H}{B}\right)^{1.283}$$

Where K = 0.067 and n = 1.283 for a sharp crested weir having different crest height and width of opening.

- The above relation can be used to measure discharge for a specified range of flows with an accuracy $\pm 5\%$

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ANNEXURE

b = 0.2 m						
P (m)	B (m)	b/B	Q_{min} (m³/sec)	Q_{max} (m³/sec)	h_{min} (m)	h_{max} (m)
0.15	1.2	0.167	0.00197	0.01069	0.0276	0.097
0.2	1.2	0.167	0.00204	0.01076	0.0255	0.096
0.25	1.2	0.167	0.00201	0.01074	0.0254	0.095
b = 0.3 m						
0.15	1.2	0.25	0.00196	0.01076	0.0197	0.073
0.2	1.2	0.25	0.00192	0.01071	0.019	0.0724
0.25	1.2	0.25	0.00199	0.01067	0.017	0.0715
b = 0.4 m						
0.15	1.2	0.33	0.00201	0.01079	0.016	0.0598
0.2	1.2	0.33	0.00201	0.01083	0.015	0.0595
0.25	1.2	0.33	0.00208	0.01076	0.0143	0.0585