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Original Research Article

Laboratory Investigation of Flow Characteristics of a Sutro Weir

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ABSTRACT

Linear proportional weirs are sharp crested weirs in which discharge of water is linearly proportional to the head over the weir crest. They tend to have high accuracy when compared with the nonlinear ones. The main objective of the study was to investigate the flow characteristics of Sutro weir as a linear weir in an open channel. In addition, the effects of the width of the base (s) and the radius (R) of the curved section on the head measured above the weir sill were monitored. The experiments were conducted in a flume having a working length of 6 m with a cross section 0.3 m wide and 0.3 m deep. A total of 45 laboratory experiments were carried out on nine different models for five different discharges. The models made of wood were grouped into two sets of which the first set consisted of five models of constant radius of 9 cm and varying base heights. The second set consisted of four models of constant weir base height of 4 cm and varying curve radius. The experimental results obtained showed that the radius (R) of the curved section had more effect on the head measured above the weir sill compared with the width of the base. The set two models showed a better linear relationship between the actual discharge and the head measured above the weir sill compared to the set one models.

1. INTRODUCTION

The ever-growing demand for water makes the understanding of water measuring techniques important and necessary. Accurate flow measurement is very important for proper and equitable distribution of water among water users. Information concerning the volume of available water is very helpful in planning for its future use and distribution. The effective use of water for irrigation requires that flow rates and volumes be measured and expressed quantitatively. Measurement of flow rates in open channels is difficult because of non-uniform channel dimensions and variations in velocities across the channel (Gertrudys, 2006).

Weirs allow water to be routed through a structure of known dimensions, permitting flow rates to be measured as a function of depth of flow through the structure. Allen and Dalton (2002), mentioned that one of the simplest and most accurate methods of measuring water flow in open channels is by the use of weirs.

A weir is basically an obstruction in an open channel flow path. A weir functions by causing water to rise above the obstruction in order to flow over it. The height of water above the obstruction correlates with the flow rate, so that measurement of the height of the flowing water above the top of the weir can be used to determine the flow rate by the use of an equation, graph or table. Weirs are typically classified as being either sharp-crested or broad-crested. Sharp crested weirs are widely used for the purpose of flow measurement, flow diversion and water level control in hydraulics, irrigation canals, laboratories and as dam instrumentation device (Alwan and Mohammed, 2016). Rectangular, triangular, cipolletti, circular and Sutro are some of the important types of sharp crested weirs (Novak and Cabelka, 2000).

Proportional weirs have profile which ensures a certain relationship between the head on the weir and the discharge. Linear proportional weirs are used as flow measuring devices, and as outlets for settling basins, grit chambers and dosing siphons (Arora, 2005). There are various types of linear proportional weirs depending on the shape of the base profile, which may be parabolic, triangular, trapezoidal or rectangular.

The Sutro weir is the most common of the linear proportional weirs with rectangular bottom sections. It belongs to a group of weirs generally referred to as compensating weirs because it has two separate profiles – the top and the base (Nistoran et al., 2019) The sutro profile is asymptotic at the bottom leading to an infinitely wide base (Pratt, 1914). Sutro tried to overcome this by assuming a known base in the form of a rectangular weir of depth, s, above which the weir profile is fitted. Keshava and Sashagiri (1989) presented a generalized mathematical theory of proportional weirs, and supported their theory with experimental verification. From the point of view of constructing the linear weir profile, the profile computations suggested by earlier investigators involve complex mathematical expressions. In engineering field applications, it is necessary to seek a solution which ensures ease of construction of the weir and provides the required accuracy in the linear head-discharge relationship. This was the motivation for Sutro in 1914 to develop a practical linear proportional weir and is known as the Sutro weir. A designed shape is fitted for the Sutro weir which has a rectangular base. The linear proportional weirs have higher accuracy with minimum error, as compared to rectangular and triangular weirs in similar situations (Swamee et al., 1991). There have been several works carried out on the discharge characteristics of proportional weirs. Leonard, (1975) carried out an experiment on a practical proportional weir consisting of a pair of quadrants of a circle. He observed that the plot of discharge (Q) against head measured above the sill (h_d) passed through the origin which demonstrated the linear relationship between Q and h_d. Lakshmana and Abdul (1971) also carried out an experimental study on a linear proportional weir with a trapezoidal bottom, which showed that the coefficient of discharge, (C_d), decreases with the head, (h_d). Similarly, Baddour (2008) demonstrated the versatility of the polynomial weir by showing its ability to reproduce the behaviour of a linear weir. In essence, the aim of the present study is to determine the effect of varying the radius of the curve section in Sutro weir geometrical shape on the head of water measured above the weir sill.

2. MATERIALS AND METHODS

2.1. Experimental Models

Nine different experimental models of Sutro weirs made of wood were fabricated. The models consisted of two different sets. The first set consisted of five models of constant radius of 9 cm and a varying value of s (the base height) (Figure 1). The values of s were 12 cm, 10 cm, 8 cm, 6 cm and 4 cm as shown in Table 1. The second set consisted of four models (Figure 2) of constant value of s (4 cm) with varying radius (R) of 11 cm, 10 cm, 9 cm and 8 cm as shown in Table 2. The weir models had a constant width of 26 cm.

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Table 1: Set one model dimensions

Model no	s (cm)	h (cm)	H (cm)	x (cm)	R (cm)
1	4	6	10	8	9
2	6	8	14	8	9
3	8	10	18	8	9
4	10	12	22	8	9
5	12	14	26	8	9

Table 2: Set 2 model dimensions

Model no	s (cm)	h (cm)	H (cm)	x (cm)	R (cm)
1	4	6	10	4	11
2	4	6	10	6	10
3	4	6	10	8	9
4	4	6	10	10	8

Figure 1: Set one models with constant radius (R)

Figure 2: Set two models with constant base height (s)

2.2. Experimental Setup

The experiments were conducted in a flume having a working length of 6 m with a cross section 0.3 m wide and 0.3 m deep as shown in Plate 1. Water was circulated through the flume by an electrically driven centrifugal pump. Laboratory experiments were carried out on nine different models for five different discharges. The models were divided into two groups (Set one and Set two). Each model was placed in the flume at a distance 3 m downstream from the flume inlet. The model was glued to the bed and side of the flume as shown in Plate 2. For each model, five different discharges (flow rate of water) were allowed to flow through. The height of the water above the weir crest (h_d) was measured by a precision point gauge. The discharge was collected in a measuring channel of known dimensions. A stop watch was used to determine the rate of flow into the measuring channel. Excess flow was directed into an adjacent floor channel, separated by a dividing steel plate. Diversion of excess flow was attained by means of a trolley mounted on wheels; the trolley was manipulated along the top of the measuring channel such that the flow through the Sutro weir was discharged into the channel for a specified time.

Plate 1: Side view of the tilting flume used for the experiment

Plate 2: Plan view of the Flume with the model fixed for the experiment

2.3. Shape of the Sutro Weir

The weir has a rectangular base of length (W) and width (s) as shown in Figure 3. The weir was assumed to be symmetrical about the ordinate's axis.

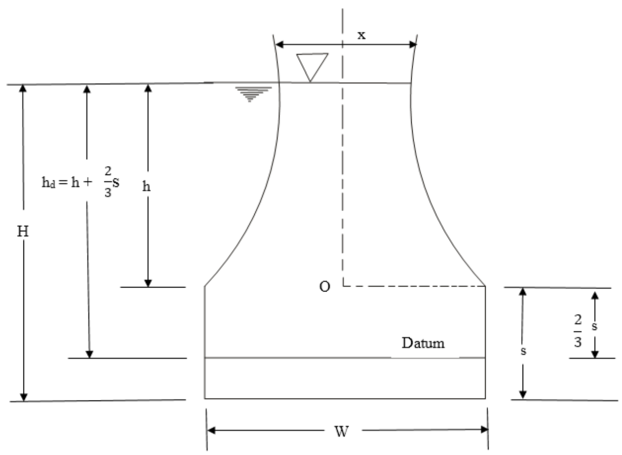

Figure 3: Flow pattern of the Sutro weir

Where x = the top width of the weir, H = the total head of the flow, h = head above the rectangular section and h_d = head over the weir sill

2.4. Weir Equation

The discharge over the Sutro weir is given by Equation 1.

$$Q = C_0 \left(h + \frac{2}{3} s\right) \quad (1)$$

Where C_0 is the proportionality constant.

$$C_0 = Wks^{1/2} \quad (2)$$

$$K = 2C_d\sqrt{2g} \quad (3)$$

h is the head measured above the rectangular base of the weir, H is the total head of the flow and h_d *is* the head over the reference plane and g = 9.81 m/s^2, C_d ranges between 0.0597 to 0.6190.

$$C_d = \frac{Qa}{Qt} \quad (4)$$

where C_d = discharge coefficient, Q_a = actual discharge (m^3/s) and Q_t = theoretical discharge (m^3/s)

$$Q_a = \frac{m}{\rho t_{av}} \quad (5)$$

where m = mass of water (kg), t_{av} = average time (sec), ρ = density of water (kg/m^3), W = length of the weir model (m) and K = coefficient that is a function of C_d

3. RESULTS AND DISCUSSION

As presented in Figure 4, the results obtained from the set one models did not particularly show a linear relationship between Q_a and h_d. This may probably be attributed to the weir dimensions considered. However, the results obtained showed that the coefficient of discharge (C_d) decreased as head (h_d) decreases as shown in Figure 5. This result is in agreement with those of Doebler and Rayfield (1973) who observed that discharges of water through the Sutro weirs have the tendency to decrease at low heads up to a certain minimum value and then increase. However, this increase was not observed in this study because low discharges were considered throughout the experiment. The discharges considered were limited by the weir dimensions which were carefully selected to fit into the flume used for the experiment. To further support this claim, Lakshmana and Abdul (1971) carried out an experimental study on a linear proportional weir with a trapezoidal bottom, and showed that the coefficient of discharge C_d decreases with a decrease head, h_d. More so, the variation in the values of 's' (the width of the base) does not really show a significant effect on the head (h_d) above the weir sill.

The set two models' results are shown in Figure 7. The Figure 7 is a combined plot of the four different models in Set two. The graph showed that there is a linear relationship between Q_a and h_d. As explained earlier in the discussion of Set one results. The set two models showed similar trend of decrease in coefficient of discharge (C_d) as head (h_d) decreased as shown in Figure 8. However, set 2 models with varying radius show that smaller radius has more effect on h_d compared with the bigger ones. In addition, Sandoval-Mendoza et al. (2017) developed a mathematical model for estimating flow in Sutro weir. One of their findings was that discharge coefficient determined experimentally are not always constant rather it varies. This assertion conforms to the result obtained from both sets of models.

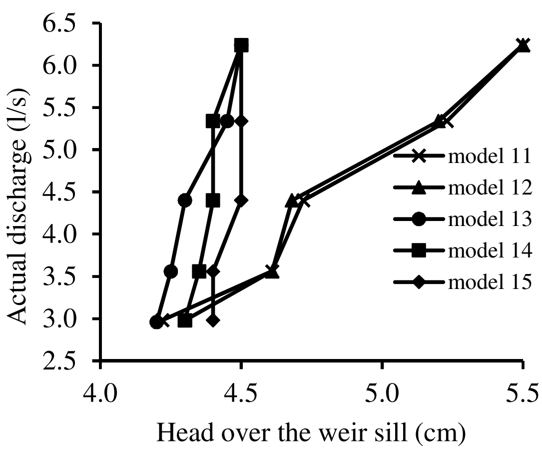

Figure 4: Variation of Q_a with h_d (Set one combined)

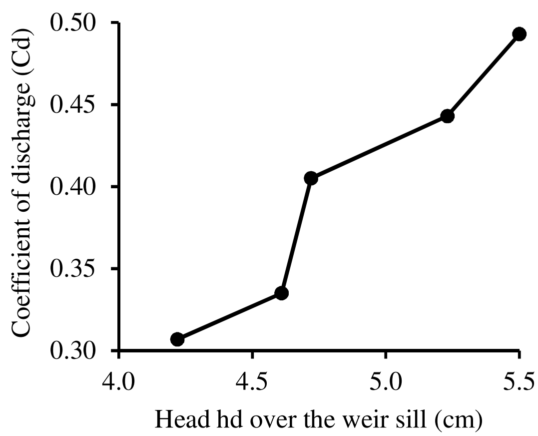

Figure 5: Plot of C_d Vs h_d (set one)

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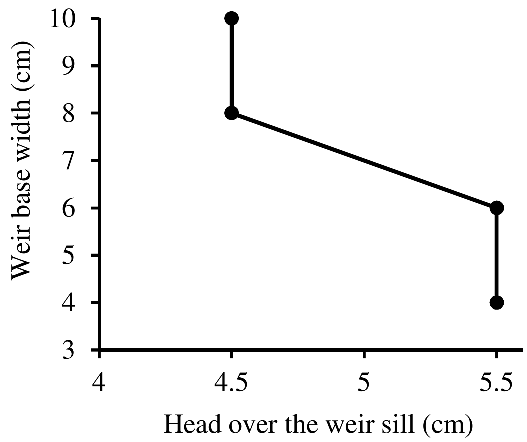

Figure 6: Plot of s vs h_d

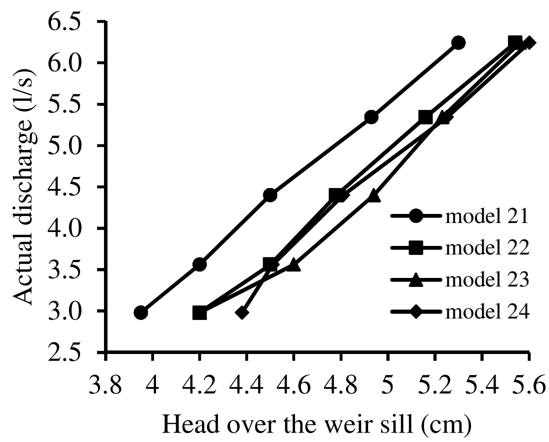

Figure 7: Variation of Q_a with h_d (set two combined)

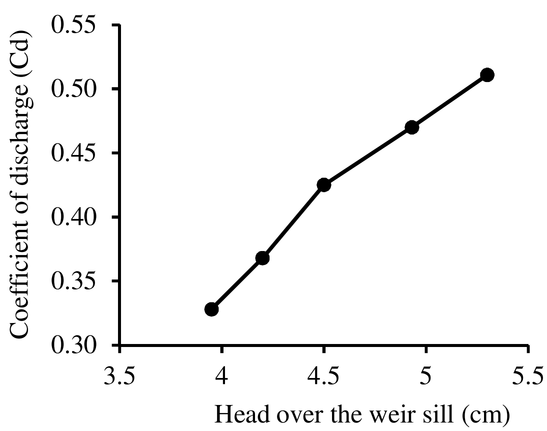

Figure 8: Plot of C_d Vs h_d (set two)

4. CONCLUSION

Based on the results obtained from the experiment, the Set two models with varying curve radius showed that changing the radius of the curve section has noticeable effect on the head measured above the weir sill compared to changing the base height.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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