Experimental Study for Measuring Flow Rate Using Broad-Crested Weirs

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Abstract- **The broad-crested weir consider as a hydraulic components frequently used in irrigation as well as in drainage networks and water treatment plants. A rectangular broad-crested weir has various merits where it is essential to determine the measurement of a variety of discharges on natural streams. The laboratory measures used in this study were taken on a rectangular broad-crested weir shape at various flow rates to test the flow pattern above a rectangular broad-crested weir. Furthermore, a formula to calculate the discharge coefficient of rectangular broad-crested weirs is also offered to compare the flow rate obtained by using the weirs with actual flow meter readings. As a result, the outcomes of the study indicated the coefficient of discharge (C_d) value increases with increasing the ratio (H/P_w) for each flow state.**

Keywords- **Broad-crested weir; Coefficient of discharge; Hydraulic structures; Elevation head.**

I. Introduction

A weir is equipment used to measure control flow in open channels and discharge such as canals. Weirs are frequently applied structures in drainage networks and ecological developments for water surface regulation and also for flow measurement. Weirs are simple, accurate, and traditional equipment used for flow measurement in open channels in the site and additionally in the laboratory (Kumar, Ahmad, & Mansoor, 2011).

Among the several types of overflow structures, a broad-crested weir has a flat crest overhead which the streamline is almost symmetric and straight. Furthermore, A variation of cross sections can be used in the section of control of broad-crested weirs depending on the requirements (Göğüş, Defne, & Oezkandemir, 2006). They are available as different kinds of configurations, such as completely scowling, slightly scowling and as full-width weirs.

Additionally, the configurations of weirs mostly come in the shapes of trapezoidal, triangular, and rectangular (Bos, 1989). Basically, in open channels with free flowing water, hydraulic structures have been installed to assess the discharge according to the measured of upstream water level (Boiten, 1993). Weirs are considered as a hydraulic construction that consists of a barrier that raises the level of water and is usually used to determine discharge. In hydraulic constructions, low measurement can be divided into two techniques, hydraulic head and velocity areas. Flow discharge is determined in the first method using the flow reach to calculate the hydraulic head difference, whereas flow discharge is determined in the second method to calculate the local velocities as well as their affected areas.

These techniques are commonly based on experimental equations they occasionally deviate from field measurements between discharge and flow head (Harrison et al., 1969). When the crest is "wide" and the pressure distribution is hydrostatic, the streamlines align with the crest invert. This simple construction has frequently existed in irrigation systems, hydroelectric systems, and freeways (Hoseini, 2014). Weirs are a sort of hydraulic structure that is been used in irrigation systems adjusting the level of water, measure flow, and divert water. The portion upstream of the structure has a connection between the discharge and head while the flow is flowing over the weir, transforming it into a control section (Mahtabi & Arvanaghi, 2018).

Many studies, as well as the studies cited previously, have been investigated the impacts of various broad crested weir projects on the characteristics of flow, with the majority of designs focusing on trapezoidal and rectangular shape of broad crested weirs. Therefore, the aims of this study is to investigate the coefficient of discharge using broad-crested weir rectangular shape and additionally, laboratory measurements were taken in order to study the flow behavior on top of rectangular broad-crested weir. Furthermore, to find out the discharge coefficient of rectangular broad-crested weirs, as well as to compare the flow rate obtained by using the weirs with actual flow meter readings.

II. Literature Review

(Göğüş et al., 2006) Had been conducted a sequences of a research laboratory tests to determine the effects of rectangular broad-crested weir with a smaller weir crest width and step height composite shape on the discharge coefficient. However, to create compound cross sections, three groups of step heights as well as three groups of lower weir crest widths were combined. Furthermore, for each experiment measurements were made of sill-referenced placed at the access channel and the downstream channel. The discharge coefficient values were

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investigated in relation to model parameters and these values were compared to those of rectangular cross-section broad-crested weir model.

(Farhoudi & Shokri, 2007) had been studied the features of flow on broad-crested rectangular weirs with slanted downstream faces. Their research measured the sensitivity of weir discharge performance to downstream sinking ratio as well as the effect of downstream slope on weir discharge effectiveness. (Gonzalez & Chanson, 2007) had been conducted a research of a full-scale broad crested weir in order to investigate the swift delivery of pressure and velocity at the weir crest's upstream end. Results showed that an overhanging crest design had an effect on the flow field, implying that more research should be done for flow circumstances in different weir geometries. (Haddadi & Rahimpour, 2012) Investigated a series of laboratory experiments of flow above a rectangular channel-shaped, trapezoidal broad-crested side weir operating in subcritical flow circumstances has been presented. According to their results indicates the coefficient of discharge of a trapezoidal broad-crested side weir is linked to the Froude number upstream of weir.

(Guven, Hassan, & Sabir, 2013) studied experimentally the hydraulic features of flow through box culverts and over a large crested weir. In a 12 m laboratory flume, twelve models of a complex broad crested weirs and box culverts been constructed and verified. Based on dimensionless concepts, the discharge coefficient predicting equations were advanced. For all models and flow states, the results indicated that coefficient discharge increases as the weir crest height to total head of water above the weir crest ratio H/P rises. (Irzooki, Akib, & Fayyadh, 2014) carried out research on the flow characteristics of weirs with semicircular openings. For each radius of the weir opening, four radii and three crest heights with a sharp or semicircular form were chosen. The results reveal that, for the same crest height and water depth over the crest, the flow going through the weir rose as the radius of the semicircular opening increased. (Pandey, Mittal, & Choudhary, 2016) had been carried out an experimental study By adjusting the weir width and weir height in a rectangular channel (9.4m x 0.6m x0.6m) with contracted acute crested rectangular weir. The research was carried out in a horizontal channel of width. The influence of weir width and weir height has been studied in this study by altering the discharge for each weir plate. Graphs were used to investigate the fluctuation in the coefficient of discharge (Cd) as a function of Reynolds Number.

III. EQUIPMENT AND EXPERIMENTAL PROCEDURE

The experimental method comprises of open flow channel and a broad-crested weir in a shape of rectangular. The width of main channel is 200mm with the 3m high × 5m long. The channel is composed of a vertical glass sidewall and a smooth horizontal brass bed. In addition, to control flow depth, a sluice gateway is installed at main channel's end. Above the rectangular broad-crested weirs, a digital point device with a sensitivity of 0.01 mm is installed. In this study, seven rectangular broad-crested weirs with varying flow rates were adopted. The sump tanks are filled to at least 3/4 full with water. Furthermore, through a supply pipe from a swamp, water for the main channel was supplied. In addition, the gate valve organized the flow. Furthermore, Measure the elevation head of the weir accordingly. Adjust the flow rate and take elevation head readings for seven different flow rates. Furthermore, by compare the results obtained by the experiment with actual flow rate measured by the flow meter. The depth of water was determined by employing a point gauge above the weirs. The details of rectangular broad crested weirs were shown in table 1.

IV. GOVERNING EQUATION

An experimental study in the laboratory was planned to investigate this possibility. Relationships among of discharge and the head for weirs have been established by many researchers. A broad-crested weir's discharge relation expressed in writing using continuity and Bernoulli's equations (Bagheri & Heidarpour, 2010).

$$Q = C_{wb} b g^{1/2} (2/3)^{3/2} H^{3/2} \quad (1)$$

Where (C_{wb}) is discharge coefficient of the weir, (b) is width of the weir, (g) is the gravitational acceleration, (h) is head of water on the weir crest, and (y_c) is cross-sectional area and critical flow depth at the control section, (C_{wb}) is influenced by the channel's and weir's flow characteristics and geometry. Description Sketch details of Channel with flow through Broad-crested weir shown in figure 1.

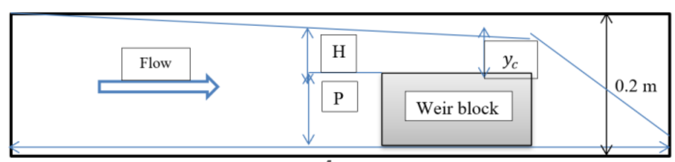

Fig.1.Description Sketch details of Channel with flow through Broad-crested weir

To measure the elevation head, the measuring point should be placed at a distance of approximately 4 times the elevation head before the weir. The coefficient of discharge (C_d) for weir calculated by dividing the practical flow rate (Q_a) by the theoretical flow rate (Q_T). In addition (C_d) is (Dimensionless). As a result, the coefficient of weir, (C_{wb}), is equal to 1.705 x C_d, which typically equal to 1.6 or typically value of (C_{wb}), or simply by using the formula (Kandaswamy & Rouse, 1957).

$$C_{wb} = 0.65/ (1+ H/P_w)^{1/2} \quad (2)$$

V. RESULT AND DISCUSSION

The weir is calculated for the respective elevation as shown below:

$$C_{wb} = \frac{0.65}{\left(1 + \frac{H}{Pw}\right)^{0.5}}$$

The respective Q_T is calculated using the formula below, shows the Q_T for calculated weir C_{wb}.

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$$Q = c_{wb}\, b \sqrt{g}\, (\tfrac{2}{3})^{3/2} H^{3/2} \qquad (3)$$

The coefficient discharge C_d is calculated using the formula below:

$$C_d = \frac{QA}{QT} \qquad (4)$$

TABLE 1
DETAILS OF RECTANGULAR BROAD CRESTED WEIRS

Type of weir	Flow rate, Q (m^3/sec)	Elevation Head, H (mm)
CBC 1	205	26
CBC 2	248	36
CBC 3	302	43
CBC 4	346	49
CBC 5	408	55
CBC 6	449	64
CBC 7	501	71

TABLE 2
EXPERIMENTAL RESULTS FOR FLOWS OVER COMPOUND BROAD-CRESTED WEIRS

C_{wb}	Q_T (m^3/sec)	C_d
0.612	27665.53	$7.41*10^{-3}$
0.607	44706.43	$5.54*10^{-3}$
0.608	58456.64	$5.16*10^{-3}$
0.608	71109.12	$4.86*10^{-3}$
0.610	84840.16	$4.80*10^{-3}$
0.608	106145.39	$4.23*10^{-3}$
0.608	124027.70	$4.04*10^{-3}$

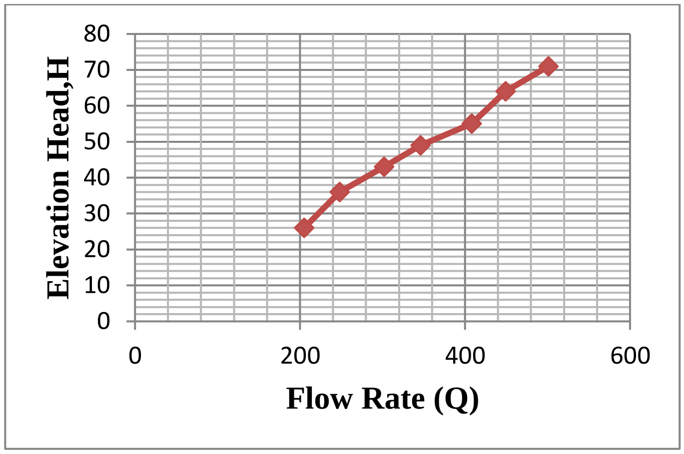

Fig.2.Flow rate (Q) vs. Elevation Head

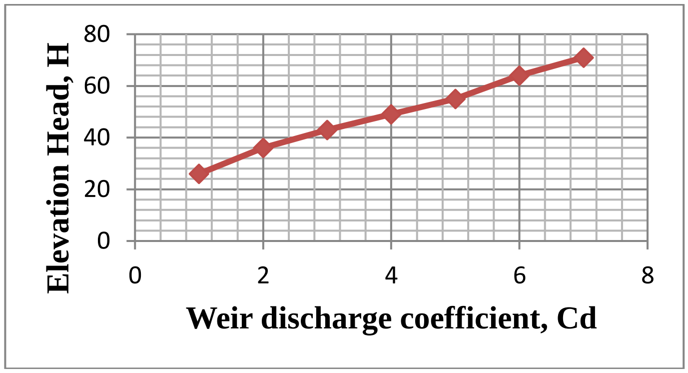

Fig.3. Weir discharge coefficient (C_d) vs. Elevation Head

The current study investigates the difference in the discharge coefficient of a rectangular broad crested weir with a diverse flow rates placed along of rectangular main channel. In order to determine spatial discharge ratio laterally the broad-crested side weir. Furthermore, mathematical model also obtained. Under subcritical flow conditions, Data from measurements were compared to the generated mathematical model. It was discovered that the provided model makes it possible to estimate the discharge coefficient along the side weir accurately. According to experimental results, following conclusions are stated below:

1. It had been discovered when the discharge coefficient grew as the magnitude of the flow rate increased. Furthermore, as shown in Figure 2, for each flow condition, H/P increases as there is an increase in the total head of water over the weir crest divided by the height of the weir crest, the discharge coefficient does as well. This could be as a result of the shape of the weir, which had a rectangular control section. More friction may have been released due to the water's rising height as the flow increased.
2. The discharge coefficient (C_d) was plotted versus upstream head ratio, as shown in figure 3 indicates that C_d increases as elevation head increases. The discharge coefficient C_d is based on effective weir length and total upstream head, so a longer weir would increase flow without increasing upstream head as

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much as a shorter weir and the crest shape could also affect upstream head.

VI. Conclusion

In the present study, the characteristics of flow over broad-crested weirs were investigated experimentally. This experimental study involved sequences of laboratory tests in order to examine how the interaction of flow over a broad crested weir affected the discharge coefficient (C_d). A smooth flow to and over the weir is essential for calculating the proper rates of flow because the distribution of velocities on the approach flow has a major impact on the discharge over the weir. For all of the investigated tests and for each flow condition, the coefficient of discharge (C_d) value increases with the ratio (H/P_w), correspondingly. The estimated values from the prediction equation and the measured values exhibit good agreement. As a result, a credible equation for the discharge coefficient of rectangular broad-crested weirs is presented.

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