American Journal of Biomedicine and Pharmacy
https://biojournals.us/index.php/AJBP
ISSN: 2997-7177

Study the Impact of Surface Roughness on the Flow Characteristics at the Downstream of a Broad-Crested Weir

Ali Al-Ridha Jaafar Razzaq, Baneen Ahmed Hussein
University of Babylon, College of Environmental Engineering

Received: 2024, 15, Nov
Accepted: 2024, 21, Dec
Published: 2025, 13, Jan

Annotation: Weir is usually incorporated as a control or regulation device in hydraulic systems, with flow measurement as their secondary. It is normally intended for use in the field and thus to regulate broad discharges. Broad-Crested weir is among the oldest common weir types. In this paper, the effect of height and surface roughness for different Board Crested weirs models were studied on discharge coefficient (Cd) in a horizontal open channel. In the crest of the weir, certain materials may be combined with concrete (e.g., boulders) or may be used as cladding to minimize the effect of water overflow (e.g. stone). The weir surface should not be considered smooth in this case, and the discharge coefficient (Cd) must be re-estimated. For these purposes, laboratory flume was used to study the effect of height and surface roughness on the discharge coefficients with six of the different broad crested weirs models dimensions of the concrete blocks. In this study, the flow conditions were considered to be free water flow and the viscosity effect was neglected. The results showed that the discharge coefficient Cd decreases as the increasing roughness of the broad weir crest surface for a given (H/H+P). The discharge coefficient Cd increases with increased (H/H+P). For group 1, the average value of the discharge coefficient was 0.66, 0.65, and 0.64 in the case of a smooth surface (case 1), in the case of a rough surface covered by gravel (case 2), and in the case of a rough surface covered by boulders (case 3), respectively. For compassion between cases 1 and 2, and also between cases 1 and 3, the percentage of a decrease in coefficient of discharge was around 2% and 3.5%, respectively. For group 2, the average value of the discharge coefficient was 0.63, 0.62 and 0.61 in the case of a smooth surface (case 4), in the case of a rough surface covered by gravel (case 5) and in the case of a rough surface covered by boulders (case 6), respectively. For compassion between cases 4 and 5, and also between cases 4 and 6, the percentage of a decrease in coefficient of discharge was around 1.75% and 3%, respectively. The best curve-fit equations have been created.

1.1 Introduction

The weir is the most commonly used hydraulic structure, because of its simple design and operation. Weirs are an open-channel flow measurement device that combines hydraulic characteristics of both weirs and channels. As common hydraulic structures, low weirs are widely used to increase the upstream water level and to measure discharge in irrigation systems. Rectangular weirs with a finite crest width are often used for the determination of discharge capacity. The most commonly used types of weirs in practice are broad-crested weirs, sharp-crested weirs, and ogee-crested weirs. These structures are built for measuring the flow in the open channel systems. Among the types of weirs, ogee crested weirs are characterized by complex geometry and are costly during construction. In addition, this type of weir is very difficult to deal with during the rehabilitation of old dams. This challenge occurs due to the topography of the dam site and restrictions on the structures of dams. The broad-crested weir is characterized by the geometry of a flat structure and the length of the crest is large enough compared to the flow thickness over the crest. The crest is labelled broad when the streamline flows are parallel to the crest and the critical depth is present. Along the crest of a broad-crested weir, the pressure distribution is hydrostatic Mahtabi and Arvanaghi (2018). Broad- crested weirs are typically much more robust than the thin plates used for constructing sharp-crested weirs. Their increased durability contributes to their extensive use for flow measurement and water level regulation in small to medium-sized rivers and canals. Typically, they are constructed out of reinforced concrete and span the width of the channel. Their rating curves rely on the flow over the crest of the weir passing through the critical depth. When the weir is constructed to a height large enough to ensure that the critical depth occurs over a crest, a rating curve can be calculated based on the geometry of the critical section. This rating curve allows for a simplified determination of the discharge by only looking at the depth of the water's surface (Julian, 2014). Significant head loss and deposition of sediment will occur upstream of a weir when the shape of the weir is vertical upstream. This will adversely affect the accuracy of the discharge measurement and increase the operating costs. To deal with such problems, the broad-crested weir's structural design can present flexibility to provide better hydraulic characteristics and discharge efficiency. Broad-Crested Weir is Classified as a structure that streamlines run parallel to each other a minimum of for a short distance, so as that a hydrostatic pressure distribution could even be assumed at the control section (Chanson, 2004; Sargison and Percy, 2010). To induce this condition, the length within the direction of the flow of the weir crest (L) is restricted to the total upstream energy head over the crest (H+P) as shown in Figures 1.1 and 1.2.

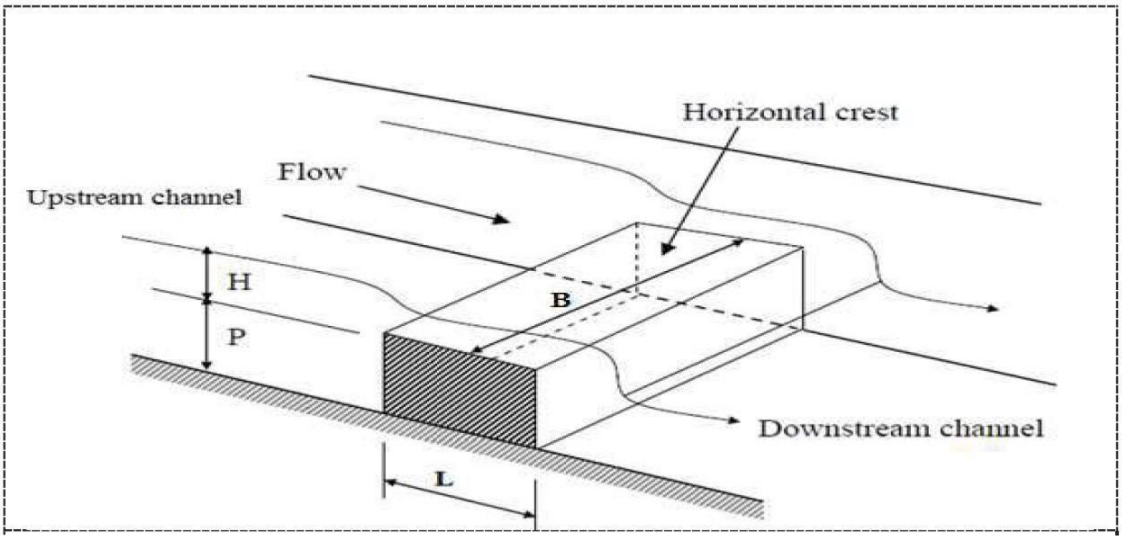

Figure 1.1: Sketch for Broad-Crested Weir.

Figure 1.2: Broad-Crested Weir in the Field.
Source: https://wiki.tuflow.com/index.php?title=File:Broad-crested_weir.jpg

1.2 Broad-crested Weirs

Broad-crested weirs' are those structures over which the streamlines run parallel to each other at least for a short distance, so that a hydrostatic pressure distribution may be assumed at the control section. To obtain this condition, the length in the direction of flow of the weir crest (L) is restricted to the total upstream energy head over the crest (H1) (Sturm, 2001and Chanson,2004).

There are many different types of broad-crested weirs, the most common ones being the horizontal broad-crested weir and romijn movable measuring/regulating weir (Bos, 1985).

1.2.1 Horizontal broad-crested weir

The Horizontal broad-crested weir is in use as a standard discharge measuring device and, as such, is described in the British Standard 3680, 1969. The weir comprises a truly level and horizontal crest between vertical abutments. The upstream corner is rounded in such a manner that flow separation does not occur. Flow separation also can be avoided by using an upstream ramp which slopes between 2 to 1 and 3 to 1 (horizontal to vertical). This upstream sloping face is a cost effective solution if the weir is constructed in concrete. Downstream of the horizontal crest there may be a vertical face or a downward slope, depending on the submergence ratio under which the weir should operate at modular flow. The weir structure should be rigid and watertight and be at right angles to the direction of flow.

The minimum radius of the upstream rounded nose (r) is $0.11H_{1max}$ although for the economic design of field structures a value $r = 0.2\ H_{1max}$ is recommended.

The length of the horizontal portion of the weir crest should not be less than $1.45\ H_{1max}$.To obtain a favorable (high) discharge coefficient (C_d) the crest length (L) should be close to the permissible minimum. In accordance with Section2.2 of BS 3680, 1969, the head measurement section should be located a distance of between two and three times H_{1max} upstream of the weir block. According to BS 3680, 1969, the basic stage-discharge equation for abroad-crested weir with a rectangular throat reads:

$$Q = C_d C_v \frac{2}{3}\sqrt{\frac{2g}{3}}\, b_c\, h_1^{1.50} \quad \text{……………………. 1.1}$$

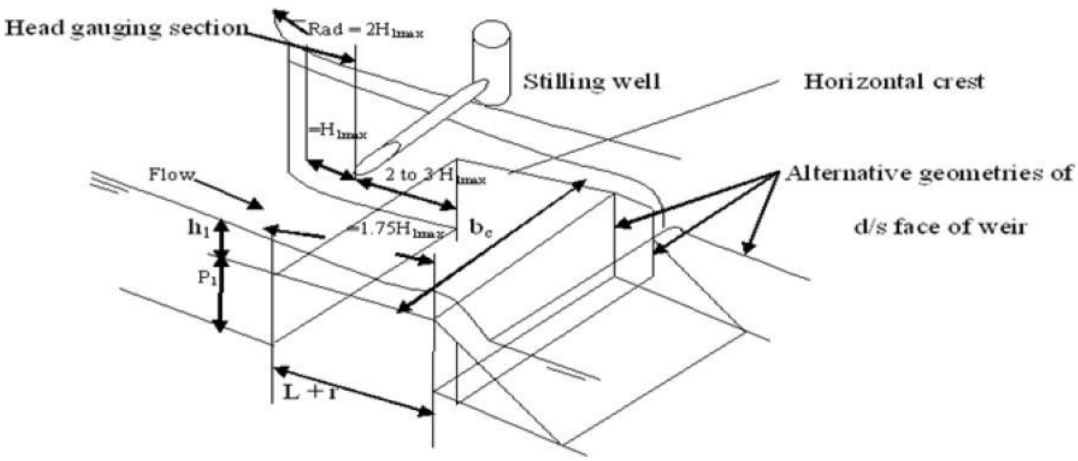

Figure 1.3: Horizontal Broad-Crested Weir (BSI 1969)

For water of ordinary temperatures, the discharge coefficient (C_d) is a function of the upstream sill-referenced energy head (H_1), and the length of the weir crest in the direction of flow (L). It can be expressed by the equation (Bos, 1985).

Cd = 0.93 + O.IO H1/L 1.2

The error in C_d of a well maintained broad-crested weir, which has been constructed with reasonable care and skill, can be deduced from the equation (Bos 1985).

Xc = ± (3 | H1/L - 0.55| + 4) per cent 1.3

1.2.2 The Romijn movable measuring/regulating weir

The Romijn weir was developed by the Department of Irrigation in Indonesia as a regulating and measuring device for use in relatively flat irrigated regions where the water demand is variable because of different requirements during the growing season and because of crop rotation (Bos, 1985).

The telescoping Romijn weir consists of two sliding blades and a movable weir which are mounted in a steel guide frame:

a. the bottom slide is blocked in place under operational conditions and acts as a bottom terminal for the movable weir

b. the upper slide is connected to the bottom slide by means of two steel strips placed in the frame grooves and acts as a top terminal for the movable weir;

c. the movable weir is connected by two steel strips to a horizontal lifting beam.

The weir crest is horizontal perpendicular to the flow and slopes 1-to-25 upward in the direction of flow. Its upstream nose is rounded off in such a way that flow separation does not occur. The operating range of the weir equals the maximum upstream head (h,) which has been selected for the dimensioning of the regulating structure.

1.3 Advantages and Disadvantages of Using Broad Crested Weirs

1.3.1 Some advantages of using broad-crested weirs for flow measurement and regulation:

- Broad-crested weirs can be computer calibrated.
- Structural stability up to a 2 to the 3m head may easily be accomplished.
- Concrete may be used as a material with the steel upstream corner for abrasion protection.
- Low cost and extremely low sensitivity to tailwater submergence.
- Cost effective installation due to the ease of design and construction.
- Relatively small head loss across the structure.
- Sturdy and capable of measuring discharge in small to medium channels.
- Theoretical calibration possible based on post-construction dimensions; and
- Capable of passing floating debris.

1.3.2 Some disadvantages of using broad-crested weirs for flow measurement and regulation:

- It may interfere with a fish passage and disrupt the ecological equilibrium;
- Sediment deposition occurs on the upstream side of the structure, leading to lower sediment flow downstream and higher water levels upstream of the weir;
- The channel immediately upstream of the weir is susceptible to sediment deposition, which in turn can compromise the accuracy of the rating curve.

1.4 Research objective

The present project aims to study the impact of size and surface roughness on the flow characteristics at downstream of a broad-crested weir.

2. Theory and Literature Review

2.1 Introduction

The characteristics of the flow over a broad-crested weir with different upstream cross-sections have been of interest to many investigators. Broad-crested weirs are among the major types of measuring structures which, because of their low cost, easy installation and high accuracy, have attracted significant attention. For better capacity and hydraulic efficiency, many researchers have carried out both experimental and numerical investigations on square-edged broad-crested weirs. Most of the analysis on various shapes of weirs has been done by modification of up and downstream faces to the inclined, and around the edge.

2.2 Literature Review

The hydraulic properties of broad crested weirs are generally expressed by the coefficient of discharge C_d that characterizes the linear relationship between the flow rate Q and the overflowing head H. Broad-crested weirs with the H / L ratio ranging from 0.02 to 1.9 and H / P from 0.1 to

0.9 were studied by Govinda Rao and Muralidhar in 1963, and then discharge coefficient C_d values were found. They seem to be the first to propose the division of finite crest length weirs into four groups of long-crested, broad-crested, short-crested, and sharp-crested weirs (Govinda and Muralidhar,1963). Azimi and Rajaratnam, (2009) proposed that C_d relies mainly on the ratio of the upstream head to the weir length in the direction of flow H / L and that if H is greater than 3 cm, the effects of viscosity and surface tension may be ignored (Horton, 1907). A classification of flow over weirs of finite crest length based on H /L was proposed by (Singer ,1964). He considered the range of H /L from 0.08 to 0.33 and found that Cd is constant with a value of 0.85 for the H/ (H+P) range from 0.18 to 0.36, where H/ (H+P) accounts for the velocity of the flow entering the weir. Azimi and Rajaratnam (2009) ignored the correction of the discharge equation velocity head and established a new C_d equation through regression analysis with C_d experimental observation from previous studies. New C_d equations have been derived for square and round-edged upstream weirs. They divided the flat-topped weir into three groups based on the H /L ratio, such as long-crested, broad crested and short crested weirs. Most researchers defined a weir as having a smooth surface made of concrete and, in experimental studies, it can be made of other comparatively smooth materials such as plywood or fibreglass. However, Parílkova et al (2009) showed that, in the case of a low overflow head, the roughness of the surface of the broad crested weir had a significant impact on the discharge coefficient (Parilkova et al, 2009). This paper focuses on studying different models of broad crested weir in the laboratory and the effect of height and surface roughness on the discharge coefficients (C_d) with free-flow conditions. Different formulas have been developed to measure discharges over weirs. In the case of free-flow conditions, most formulas can be expressed in the following general form (Ranga, 2003; Adeogun and Mohammed, 2019).

$$Q_f = C * B * H^{1.5} \quad \text{……………………… (2.1)}$$

Where C is the weir coefficient while B and H are the width of the weir and height of water respectively . The weir coefficient C is expressed in the function of the discharge coefficient C_d from the definition of the Bernoulli equation as follows (Bos, 1989 and Asawa, 2008).

$$C = \frac{2}{3} C_d \sqrt{\frac{2g}{3}} \quad \text{……………………… (2.2)}$$

In a rectangular channel, for different H/ (H + P) ratio values ranging from 0.1 to 1.0, Ranga and Asawa proposed the formula shown below (equation 3) to find different values of discharge coefficient (C_d) and for experimental studies in the laboratory by the try and the error method (Ranga, 1979).

$$\frac{H}{H+P} = \frac{\sqrt{{C_d}^{2/3} - \frac{2}{3}}}{C_d} \sqrt{3} \quad \text{……………………… (2.3)}$$

Madadi et al. (2014) investigated whether the weir discharge coefficient will be increased when the weir upstream entrance condition changes from a square-edged to a round-nosed corner. Sargison and Percy (2009) reported that the upstream and downstream of broad-crested weirs can be sloped to prevent deposition of sediment or solids in the upstream side of the weirs, and cavitation at the downstream corner of the weir and separation zone.

Viscosity and surface tension effects are ignored if the water height is greater than 3 cm above the weir surface (Ghaderi et al, 2020). The discharge coefficient C_d is introduced to account for head loss due to weir surface roughness and the depth of the water above the weir crest is taken into account instead of the energy head i.e. the velocity head is ignored (Bos, 1989).

Tahmassebii (2010) worked on the effects of roughness on the dimensions of the separation region for broad-crested weirs. The results of this research indicated that the separation height to the water height ratio over a weir decreases as the roughness of the weir increases. Othman et al. (2010) examined the effects of three different roughness sizes and three different diameters of a cylindrical weir on the conditions of passing flows. Their results demonstrated that the coefficient of discharge and discharge passing over the weir increase as cylinder diameters decrease. In addition, the results showed that an increase in the roughness size of the weir surface leads to a significant decrease in the discharge coefficient and that the effect of RH on the discharge coefficient increases as the diameter of the cylinder increases. Othman et al. (2010) finally presented an experimental equation to estimate the flow drainage under different cylinder sizes and weir roughness. The review of research undertaken on broad crested weirs shows that the effects of upstream flows and weir dimensions on the discharge coefficient have been adequately considered, Despite this, less attention has been paid to the effects of roughness on velocity profiles as well as the discharge coefficient of broad crested weirs.

This review demonstrates that most of the experimental works have been performed towards the understanding of the flow characteristics over the weirs and also the determination of the coefficients of discharge under different flow conditions, none of these studies has searched about the effect of surface roughness of the weir on flow properties. In this project, the flow over a broad crested weir is investigated.

2.3 Estimation of Discharge and Coefficients of Discharge

Different formulas have been developed to measure discharges over weirs. In the case of free flow conditions. Henderson (1966) suggested that the discharge equation for rectangular broad-crested weirs can be written as:

$$Q = \frac{2}{3} C_{rd} \sqrt{2g} b h^{3/2} \qquad \text{………………………. (2.4)}$$

Where g = acceleration due to gravity; b = length of the weir; h = head above the weir crest; and C_{rd} = coefficient of discharge for the rectangular broad- crested weir. In a rectangular channel, for different H/ (H + P) ratio values ranging from 0.1 to 1.0, Ranga and Asawa proposed the formula that shown below (equation 2.5) to find different values of discharge coefficient (C_d) and for experimental studies in laboratory by the try and the error method (Asawa, 2008):

$$\frac{H}{H+P} = \frac{\sqrt{{C_d}^{2/3} - \frac{2}{3}}}{C_d} \sqrt{3} \qquad \text{………………………. (2.5)}$$

Viscosity and surface tension effects are ignored if the water height is greater than 3 cm above the weir surface (Ghader et al, 2020). The discharge coefficient C_d is introduced to account for head loss due to weir surface roughness and the depth of the water above the weir crest is taken into account instead of the energy head i.e. the velocity head is ignored (Bos, 1989).

The values of C_{rd} according to Henderson (1966), depend upon h (the head above the weir crest), b (weir length), P (height of the weir crest above the channel bed), and B (the channel width). Barr (1910) concluded that if B/h < 8 or if P/h < h/36, then the discharge coefficient would be influenced by the proximity of the wall and floor respectively (in other words the weir is said to be not fully contracted). Also Lenz (1943) showed that the variation of the surface tension and viscosity of water could increase the value of discharge coefficient by 1% as a result of temperature rise from 5 to 750C. Other researchers like Barnes 1916; King (1916); Greve (1932); and Hertzler (1938), proposed that the value of the discharge coefficient can be obtained from the relation.

$$C_{rd} = \frac{A}{h^b} \qquad \text{………………………….. (2. 6)}$$

where A is approximately 0.59 x 8/15√2 = 0.44 (for V- notch) with the exponent b being very small (order 0.02 to 0.03). Ackers et al (1980) attributed the apparent dependence of the C_{rd} on h to the effect of fluid properties. Furthermore, French (1986) gave the following equation for the estimation C_{rd}

$$C_{rd} = \frac{0.611+2.23\,(\frac{B}{b}-1)^{0.7}}{1+3.8\,(\frac{B}{b}-1)^{0.7}} + \frac{0.075-0.011(\frac{B}{b}-1)^{1.46}}{1+4.8\,(\frac{B}{b}-1)^{1.46}}\frac{h}{p} \quad \text{…………………. (2. 7)}$$

3. Experimental Set-Up and Test Procedure

3.1 Experimental Set-Up

3.1.1 Description of Experimental Flume

To achieve the objectives of this study, the experimental work of this study was conducted in the fluid Laboratory of Civil Engineering Department, Faculty of Engineering, University of Babylon. As shown in Figure 3.1, the experimental flume is comprised of the main laboratory flume and auxiliary flumes, The main flume with 12m in length with a rectangular section at 0.30m in width made of metal bed and 0.45m in depth with glass sidewalls; it contains a control gate placed at the end for flow depth controlling. The flume slope was adjusted to be horizontal.

Since the maximum water head over the rectangular weir crest (H= 10cm), therefore the range of an accurate head measuring distance is (0.30- 0.40m) (Bos, 1989 and Fattah et al., 2019), thus the average distance (0.35 m) from the weir was adopted in all experiments to ensure the accuracy of flow measuring. The flume contains a bed and sidewalls that were made of steel with dimensions (0.3m) width, and (0.45m) height, and with dimensions (1.10 width *1.10 length *0.45 height) m for two collecting basins. Models were installed on the main flume at (5.50m) from the main flume upstream. The main flume is fed with water by a centrifugal pump with a capacity of (27 l/s) (see Figure 3.2) which contains a control valve to control passing discharge.

Figure 3.1: Tilting Flume used for the study

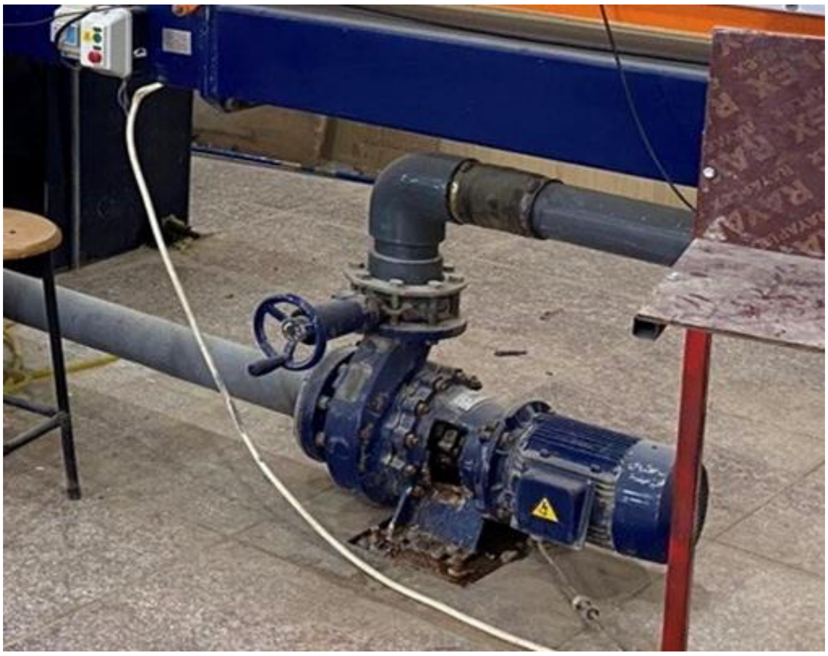

Figure 3.2: Centrifugal pump

3.1.2 Instrumentations

The water level over the weir varied from 5 to 100 mm, for various values of discharge, a digital flow meter has been utilised to measure the discharge rates as shown in Figure 3.3. A movable pointer gauge with an accuracy of ±0.001 m mounted on the flume side rails (allowing longitudinal and transverse movement) has been used to measure water depth upstream of the broad crested weir (see Figure 3.4).

Figure 3.3: Digital Flow Meter

Figure 3.4: Movable Pointer Gauge

3.1.3 Description of the Models

Concrete blocks of different dimensions by the mixing ratio (1: 2: 4) are ideal for laboratory simulation of this type of weir. six blocks of ordinary concrete were poured in the following sizes (B, P, L): group 1 consisted of three models with a size of (29.5 cm x10 cm x10 cm) and group 2 consisted of three models with a size of (29.5 cm x 20 cm x 20 cm) (see Figure 3.5). Each group was created to observe the effect of the surface roughness of the crest on the discharge coefficient by coating the weir surface with cement to get a smooth surface. The second model was coated with gravel D50 (2.5 mm), and the third model was substituting the boulder on the weir surface (Figure 3.5). Boulders of irregular form, with lengths varying from 5 to 10 cm, were used and distributed uniformly on the surface of the model. The concrete models of the weirs (six blocks of concrete) were put in the treatment basins for 7 days to harden before they were placed in the laboratory channel.

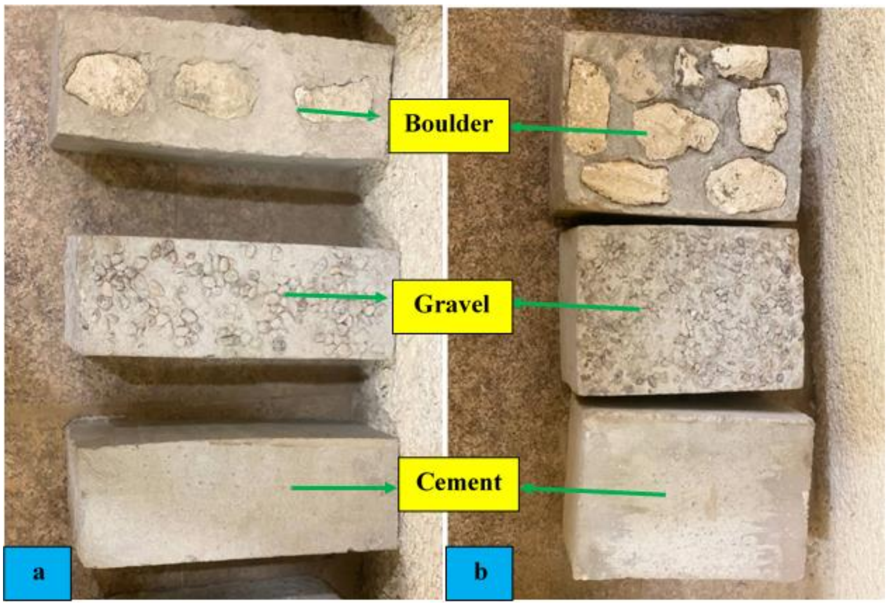

Figure 3.5: Concrete blocks of different dimensions to simulate the weir. a: group 1 and b: group 2.

3.1.4 Discharge Calibration of Rectangular Weirs

It is necessary to verify the validity of discharges passing through downstream and lateral flumes to ensure that all hydraulic parameters are accurately satisfied. Figure 3.6 shows a sharp-crested weir with a rectangular section made of steel and a distance within the permitted range to perform head measuring and obtain an accurate discharge passing the auxiliary flumes (USBR, 1997; Bos, 1989 and Fattah et al., 2019).

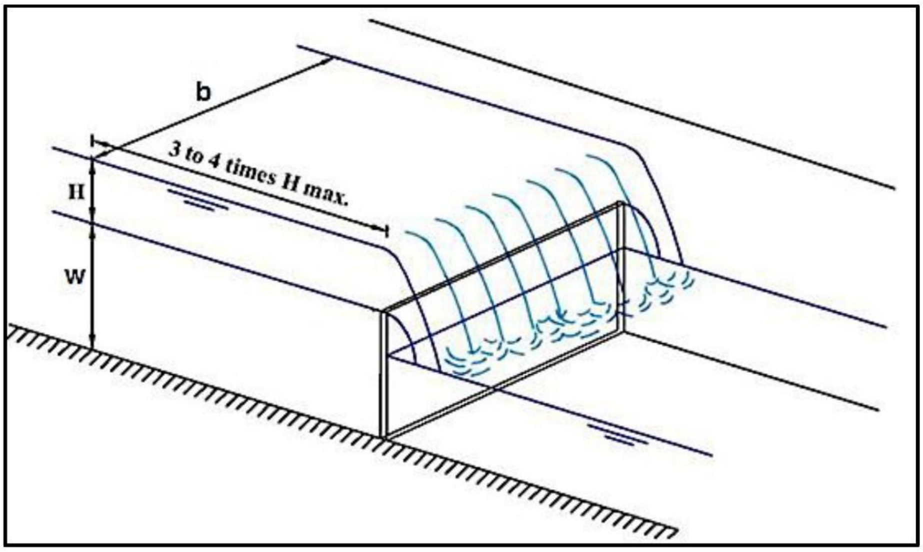

Figure 3.6: Schematic illustration of weir detail

Using the volumetric method, the calibration curves for side weir and downstream rectangular weirs were drawn by plotting the rating curve between the head (H) and the actual discharges. The calibration process has been performed by closing the downstream main flume control gate and applying various inward discharges to obtain the rating curve of the side flume rectangular weir (see figure 3.7) and obtaining the discharge equation as indicated below:

$$Q_{sw} = 0.57\ (H_s)^{1.5} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3.1)$$

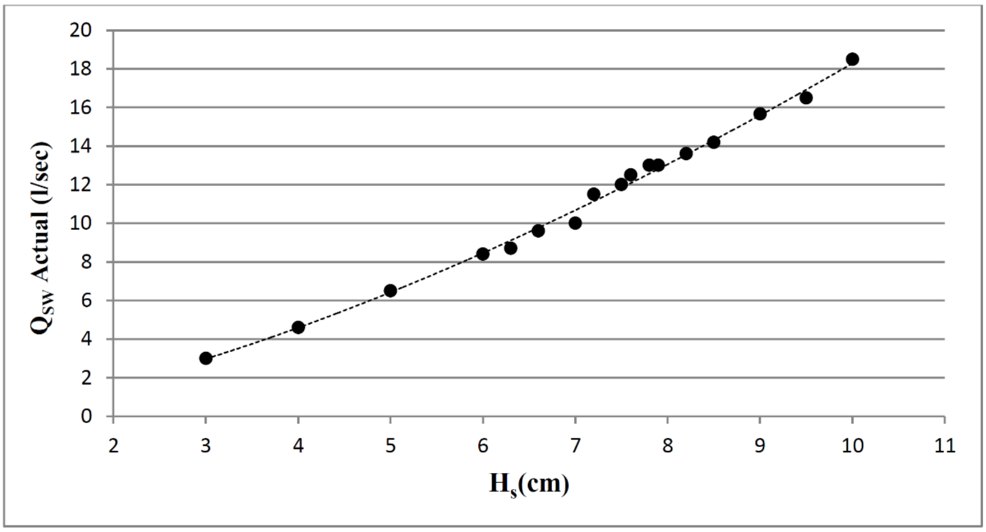

Figure 3.7: Rating curve of rectangular weir for the side flume.

3.2 Test Procedure

Laboratory experiments can be explained in the following steps:

1. Adjusting the main flume at a horizontal slope.
2. Installing the broad crested weir model into the main flume and checking the model's horizontal situation for different plans using a level meter. Then Adjusting the control gate to provide the initial water level for a particular weir height
3. Turn on the pump to start water pumping and wait for steady-state flow
4. When the steady-state of flow is attained when no water depth fluctuation is appeared and becomes almost constant, the flow depth in the main flume is measured using a point gauge device
5. Using the control valve, different inward discharges are applied, and step 4 is repeated
6. Steps (2-5) are repeated for other models.

4. Results and Discussions

It is possible to change the discharge several times by setting the L-length and measuring the value of H multiple times and applying the equation (2.4) to find different values of discharge coefficient (C_d) and for experimental studies in a laboratory by the try and error method (Adeogun and Mohammed, 2019). Tables (4.1) to (4.6) show the results of solving Equations (2.4) and (2.5) for various values of (H/(H + P)).

Table 4.1: Experimental results for concrete block covered by cement (smooth surface) and model size of (29.5 cm x 10 cm x10 cm) and P = 10 cm, (case 1).

Run No.	H (cm)	H/(H+P)	C_d	Q (m^3/sec)
1	5	0.33	0.64	$5.74x10^{-3}$
2	6	0.35	0.65	$5.83x10^{-3}$
3	7.5	0.43	0.67	$7.53x10^{-3}$
4	9.5	0.49	0.68	$10.34x10^{-3}$

Table 4.2: Experimental results for concrete block covered by gravel and model size of (29.5 cm x 10 cm x 10 cm) and P = 10 cm, (case 2).

Run No.	H (cm)	H/(H+P)	C_d	Q (m^3/sec)
1	5.5	0.35	0.63	$5.78x10^{-3}$
2	6.5	0.39	0.65	$5.83x10^{-3}$
3	8	0.44	0.66	$13.32x10^{-3}$
4	10	0.50	0.68	$17.5x10^{-3}$

Table 4.3: Experimental results for concrete block covered by boulders and model size of (29.5 cm x 10 cm x 10 cm) and P = 10 cm, (case 3).

Run No.	H (cm)	H/(H+P)	C_d	Q (m^3/sec)
1	5.5	0.35	0.62	$3.99x10^{-3}$
2	7	0.41	0.64	$5.78x10^{-3}$
3	8.5	0.46	0.66	$9.72x10^{-3}$
4	10.5	0.51	0.675	$13.32x10^{-3}$

Table 4.4: Experimental results for concrete block covered by cement (smooth surface) and model size of (29.5 cm x 20 cm x20 cm) and P = 20 cm, (case 4).

Run No.	H (cm)	H/(H+P)	C_d	Q (m^3/sec)
1	4	0.17	0.61	$3.52x10^{-3}$
2	5	0.20	0.63	$5.74x10^{-3}$
3	6.5	0.25	0.65	$6.12x10^{-3}$
4	9	0.31	0.66	$9.72x10^{-3}$

Table 4.5: Experimental results for concrete block covered by gravel and model size of (29.5 cm x 20 cm x 20 cm) and P = 20 cm, (case 5).

Run No.	H (cm)	H/(H+P)	C_d	Q (m^3/sec)
1	4	0.17	0.6	$3.99x10^{-3}$
2	5	0.20	0.62	$5.83x10^{-3}$
3	6.5	0.24	0.64	$12.32x10^{-3}$
4	9	0.31	0.65	$17.5x10^{-3}$

Table 4.6: Experimental results for concrete block covered by boulders and model size of (29.5 cm x 20 cm x 20 cm) and P = 20 cm, (case 6).

Run No.	H (cm)	H/(H+P)	C_d	Q (m^3/sec)
1	4.5	0.18	0.6	$3.99x10^{-3}$
2	6.5	0.25	0.62	$5.78x10^{-3}$
3	7	0.26	0.63	$9.72x10^{-3}$
4	9.5	0.32	0.65	$12.32x10^{-3}$

As previously stated, equation (3) holds for (H/(H + P)) ratio values ranging from (0.1 to 1).In this analysis, the (H/(H + P)) ratio ranged from 0.26 to 0.5. The relationship between the discharge coefficient Cd and the water head in upstream H/(H+P) can be determined using non-linear regression analysis. The square of the correlation coefficient R^2 is an indicator of fitness for non-linear regression models. The results were statistically analysed. This regression analysis was demonstrated through the curves shown in Figures (4.1) to (4.6). The discharge coefficient (Cd) remained directly proportional to the H/(H+P) in all cases. The regression analysis revealed a strong correlation between the discharge coefficient Cd and the ratio H/(H+P), with square values of the correlation coefficient R2 ranging between 0.96 and 0.99 in each of the six cases. As a result, the relationship between the discharge coefficient and the water head upstream of the broad crested weir was significant. Furthermore, equations were obtained for the estimation of the discharge coefficient for each of the six cases (see Figures (4.1) and (4.2)).

Figures 4.1 and 4.2 show that the discharge coefficient C_d decreases as the increasing roughness of the broad weir crest surface for a given (H/H+P). This is attributed to energy losses due to friction with a broad weir surface. Also, turbulent flow conditions are created downstream of the broad weir due to the surface roughness. Also, the discharge coefficient C_d increases with increased (H/H+P).

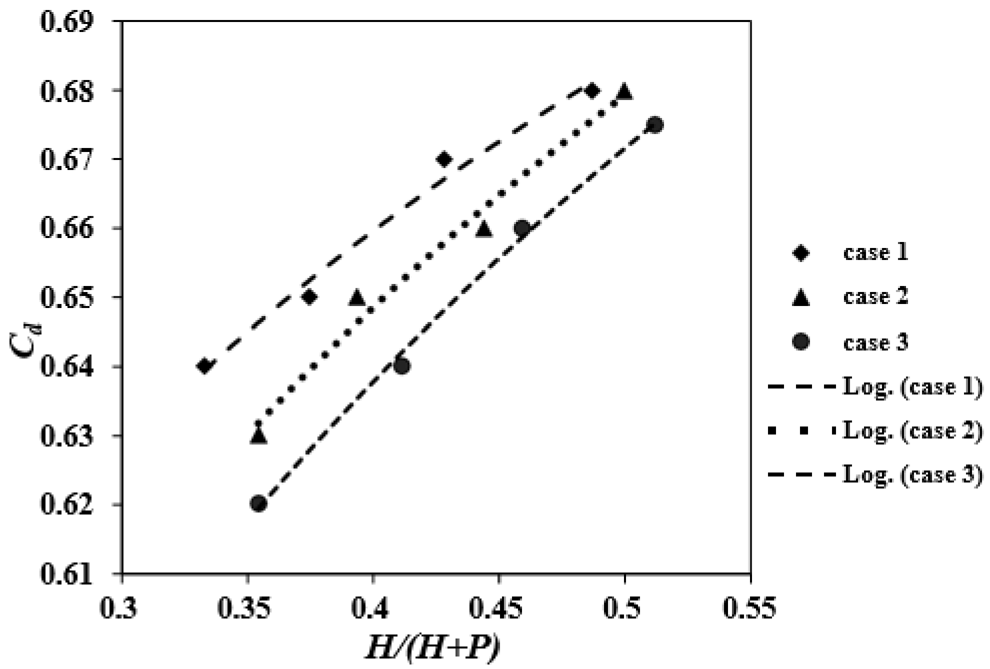

Figure 4.1: Relationship between Cd and H/(H+P) for three cases of group 1.

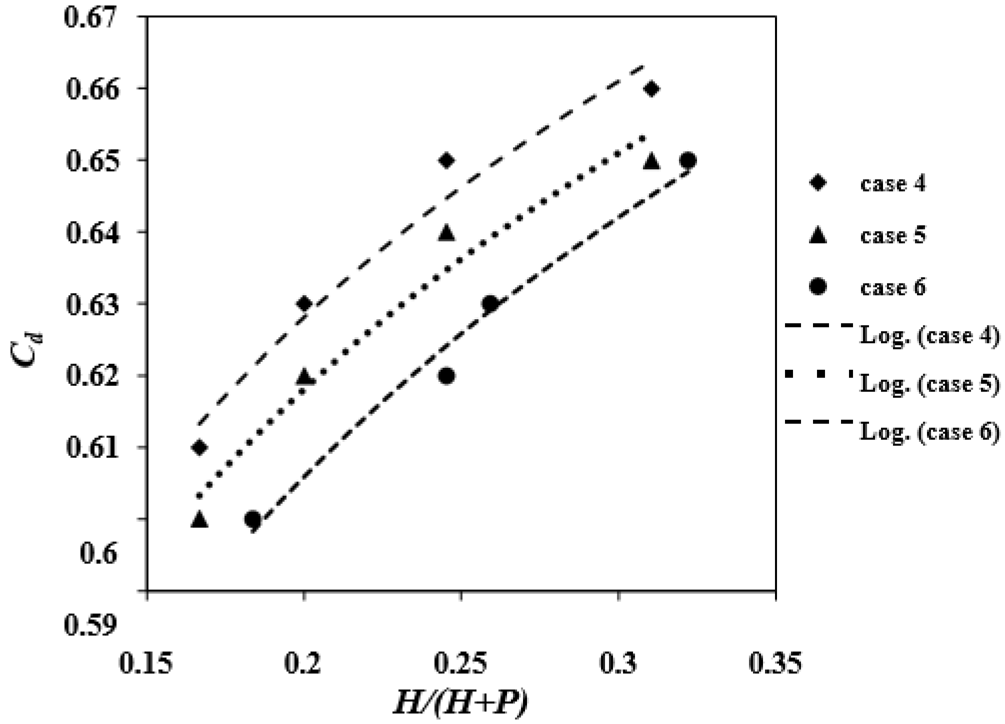

Figure 4.2: Relationship between Cd and H/(H+P) for three cases of group 2.

For group 1, the average value of the discharge coefficient was 0.66, 0.65, and 0.64 in the case of a smooth surface (case 1), in the case of a rough surface covered by gravel (case 2), and in the case of a rough surface covered by boulders (case 3), respectively. For compassion between cases 1 and 2, and also between cases 1 and 3, the percentage of a decrease in coefficient of discharge was around 2% and 3.5%, respectively (see Table 4.1, Table 4.2, and Table 4.3). For group 2, the average value of the discharge coefficient was 0.63, 0.62 and 0.61 in the case of a smooth surface (case 4), in the case of a rough surface covered by gravel (case 5) and in the case of a rough surface covered by boulders (case 6), respectively. For compassion between cases 4 and 5, and also between cases 4 and 6, the percentage of a decrease in coefficient of discharge was around 1.75% and 3%, respectively (see Table 4.4, Table 4.5, and Table 4.6).

According to the set of curves presented in Figures 4.1 and 4.2, the dashed line represents the best curve-fit equation given by Equation (4.1) that is obtained from the experimental data. The best curve-fit coefficients and R^2 are presented in Table 4.7.

Cd = A ln (-) + B………… (4.1)

H+P

Table 4.7: Curve-Fit coefficients for all cases of relationship between

Cd* and *H/(H+P).

Group No.	Case No.	A	B	R^2
Group 1	1	0.1103	0.7605	0.98
	2	0.1388	0.7755	0.98
	3	0.1524	0.7771	0.99
Group 2	4	0.0813	0.7589	0.96
	5	0.0813	0.7489	0.96
	6	0.0892	0.7495	0.98

5.1 Conclusions

Based on the analysis of experimental observations, the following conclusions are made:

1. The discharge coefficient C_d decreases as the increasing roughness of the broad weir crest surface for a given (H/H+P).
2. The discharge coefficient C_d increases with increased (H/H+P).
3. For group 1, the average value of the discharge coefficient was 0.66, 0.65, and 0.64 in the case of a smooth surface (case 1), in the case of a rough surface covered by gravel (case 2), and in the case of a rough surface covered by boulders (case 3), respectively.
4. For compassion between cases 1 and 2, and also between cases 1 and 3, the percentage of a decrease in coefficient of discharge was around 2% and 3.5%, respectively
5. For group 2, the average value of the discharge coefficient was 0.63, 0.62 and 0.61 in the case of a smooth surface (case 4), in the case of a rough surface covered by gravel (case 5) and in the case of a rough surface covered by boulders (case 6), respectively.
6. For compassion between cases 4 and 5, and also between cases 4 and 6, the percentage of a decrease in coefficient of discharge was around 1.75% and 3%, respectively.
7. The best curve-fit equations have been created.

References

1. Ackers P., W. R. White, J. A. Perkins, and A. J. M. Harrison (1980). *Weirs and flumes for hydraulic measurement*. A Wiley-Inter science Publication, Wiley and Sons, Chichester. New York. Brisbane. Toronto.
2. Adeogun A G . and Mohammed A A, (2019). *Review of Methods of Measuring Streamflow Using Hydraulic Structures* Open access peer-reviewed chapter pp 7-9
3. Adeogun A. G., and Mohammed A. A., (2019). *Review of Methods of Measuring Streamflow Using Hydraulic Structures* Open access peer-reviewed chapter pp 7-9

4. Asawa G. L., (2008). *Irigation and water resources engineering*, New Age Int New Delhi pp 193-197.
5. Azimi, A.H. and Rajaratnam, N., (2009). Discharge characteristics of weirs of finite crest length. *Journal of Hydraulic Engineering*, *135*(12), pp.1081-1085.
6. Barnes, A. A. (1916). *Hydraulic flow reviewed*. Spon, London.
7. Barr, J., (1910). *Experiments upon the flow of water over triangular notches*. Engineering (London).
8. Bos M. G., (1989). *Discharge measurement structures* 3rd Ed , International institute for land reclamation and improvement Wageningen The Netherlands pp 211-279
9. Bos, M.G. (1985). *Discharge measurement structures.* International Institute for Land Reclamation and Improvement (ILRI), publication 20, Wageningen, The Netherlands.
10. Chanson H, 2004. *The hydraulics of open channel flows: An introduction*, 2nd Ed Butterworth-Heinemann Oxford, U.K pp 48-116
11. Chanson, H. (2004). *The hydraulics of open channel flow: an introduction*. Butterworth-Heinemann, Oxford, UK, 2nd edition. Retrieved March 6, 2011.
12. Fattah, M. Y., Omran, H. A., and Matooq, J. S. (2019). Construction of Hydraulic Structures (1 st). University of Technology-Iraq Press.
13. French, R. H. (1986). *Open-channel hydraulics.* McGraw-Hill, New York.
14. Ghaderi, A., Dasineh, M., Abbasi, S. and Abraham, J., (2020). Investigation of trapezoidal sharp-crested side weir discharge coefficients under subcritical flow regimes using CFD. *Applied Water Science*, *10*(1), pp.1-12.
15. Govinda Rao, N.S. and Muralidhar, D., (1963). Discharge characteristics of weirs of finite-crest width. *La Houille Blanche*, *49*(5), pp.537-545.
16. Greve, F. V. (1932). *Flow of water through circular, parabolic and triangular vertical notch weirs.* Purdue Univ. Eng. Bull., 16, No. 2, Res. Series 40.
17. Henderson, F. M., (1966). *Open Channel Flow*, Macmillan, New York, pp. 174-
18. Hertzler, R. A. (1938). *Determination of a formular for the 1200 V-notch weir*. Civil Engineering, 756.
19. Horton R. E., (1907). *Weir experiments, coefficients, and formulas* Proc.US Geological survey Survey Water Supply, Government Printing Office, Washington, D.C.
20. Julian, D. P., (2014). Erik Sutherland Trevor Taylor, 9. classification of weirs
21. King, H. W. (1916). *Flow of water over right-angled V-notch weir.* Univ. Mich. Technic. 29, No. 3, 189
22. Lenz, A. T., (1943). *Viscosity and surface tension effects in V-notch weir coefficients.* Trans. A.S.C.E., 108.
23. Madadi, M.R., Dalir, A.H. and Farsadizadeh, D., (2014). Investigation of flow characteristics above trapezoidal broad-crested weirs. *Flow Measurement and Instrumentation*, *38*, pp.139-148.
24. Mahtabi, G. and Arvanaghi, H., (2018). Experimental and numerical analysis of flow over a rectangular full-width sharp-crested weir. Water Science and Engineering, 11(1), pp.75-80.

25. Othman, Kh.I., Tahsen, A.Ch. and Ibrahim, A.I.Al-H. (2010). Effect of size and surface roughness of cylindrical weirs on overflow characteristics, *Al- Rafidian Engineering Journal*, 19(2), 77-89.
26. Parilkova J., Pana P., Riha J., and Zachoval Z., (2009). The findings from experimental research into dike spillways .*Xii Int. Sci.Conf.* Czech Republic *pp 31-33*
27. Ranga raju K G, and Asawa G. L., (1979). *Comprehensive Weir décharge formula* proc Of IMEKO int. Conf. on flow measurment and control in industry,Tokyo Nov.1979. pp 3-7.
28. Ranga Raju, K.G., (2003). *Flow Through Open Channels* Tata McGraw Hill pp 259-331
29. Sargison J E and Percy A., (2010). Discussion of Hydraulics of Broad-Crested Weirs with Varying Side Slopes, *J IRRIGAT DRAIN ENG ASCE* 136 (7) pp 508- 509
30. Sargison, J. E., Percy, A. (2009). Hydraulics of broad-crested weirs with varying side 452 slopes. *Journal of Irrigation and Drainage Engineering*. 135(1):115- 8.
31. Singer J., (1964). *Square*-edged broad crested weir as a flow measurement device Water Eng 28 (820) pp 229–235
32. Sturm, T.W. (2001). *Open Channel Hydraulics.* McGraw Hill, Boston, USA, Water Resources and Environmental Engineering Series, 493 pages.
33. Tahmassebii, S. (2010). *Experimental Study of effect of weir crest roughness on separation region in broad crested weir*, MSc. Thesis, University of Shahid Chamran, Ahvaz, Iran.
34. USBR. (1997). Water Measurement Manual. (3 rd Editi). Denver.
35. Zachoval Z, Veselý J., and Pařílková J., (2009). Determination of the discharge coefficient of a trapezoidal broadcrested weir with a rough surface Symp. of hydro technicians Brno Czech Republic. pp. 88–94.