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An Investigating of the Impact of Bed Flume Discordance on the Weir-Gate Hydraulic Structure

Rafi M. Qasim [1], Alya A. Mohammed [1*], Ihsan A. Abdulhussein [1]

[1] *Basra Engineering Technical College, Southern Technical University, Basra 61003, Iraq.*

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Abstract

Discordance and concordance play a significant role in the hydraulic response for the flume, open channel, hydraulic structure, and flow field measurement. Bed discordance and bed concordance are regarded as common problems in open channels. Discordance is the dominant one, which could have an effect on the hydraulic structure that is constructed inside the channel. This paper deals with the impact of bed flume discordance on hydraulic flow characteristics at the weir-gate downstream hydraulic regime. Four configurations with different lengths and heights of the bed flume discordance are adopted here to investigate the impact of these configurations on the hydraulic characteristics. In addition, one configuration of the bed flume concordance is adopted to compare with the other four configurations. At downstream, the average water depth becomes dimensionless by dividing by upstream water depth, vertical distance between weir and gate, length of downstream, length of concordance, and length of discordance in order to evaluate the inequality in the distribution of Froude number. On one hand, certain results appear strongly between Reynolds number and Froude number at downstream, actual discharge and flow velocity at downstream, flow area past the gate and Froude number at downstream. On the other hand, there was a complex dramatic relation between the weir-gate discharge coefficient and Froude number at downstream. Overall, the study shows that there is a good relationship between specific energy, water depth, and flow speed.

Keywords: Bed Flume; Gate; Hydraulic Structure; Specific Energy; Weir.

1. Introduction

The water flow in the open channel with a horizontal uniform bed or bed with inclination can be considered a conventional matter, but when the horizontal uniform bed includes discordance in elevation, many problems must be avoided. In general, this arrangement would commonly affect the hydraulic open channel regime. It will also reflect, especially on the hydraulic structure that is built into the channel. The elevation discordance plays a vital role in determining the location and height of the hydraulic jump. Also, the discordance has a substantial impact on the specific energy, which is equivalent to the specific water depth. Here, discordance may be reflected positively or negatively on the relationship between the specific energy and the water depth. Overall, the discordance in bed elevation affects the discharge quantity and flow velocity. The magnitude of this influence when it is contrasted and/or becomes more sensitive, which in turn affects directly or indirectly the open channel and the hydraulic structure. At this point, bed discordance plays a significant role in the hydraulic response, sediment transport, and ecology. The surveys at river confluences always show the presence of a difference in the bed elevation between the main open channel and the tributary [1-3].

* Corresponding author: alayaalrefee@stu.edu.iq

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Furthermore, flow patterns for bed confluences containing discordant are found to be different from flow patterns for bed confluences containing concordant [3-5]. Field studies done by De Serres et al. (1999) [6] and Boyer et al. (2006) [7] denote a secondary circulation which can be developed in the lee of a bed elevation discordance of the confluence hydrodynamic zone. This advantage may be relevant not only to the scouring and mixing processes, but also to its interaction with the other advantages of the open-channel confluence, which are significant for the head losses and, as a result, the backwater influences caused by the confluence. Laboratory experiments discovered important differences in flow and turbulence characteristics between concordant and discordant bed confluences [3, 4]. Ramos et al. (2019) [8] studied the impact of the bed elevation discordance on the flow patterns and head losses in a right-angled confluence of an open channel with rectangular cross-sections. They did a numerical model based on a large eddy simulation, and then they did a validation of the model with the cooperation of the experiments done by others. Here, four configurations are used with various bed discordance ratios. Ramos et al. (2018) [9] used a large eddy simulation to investigate the impact of the head losses and the dimensions of the recirculation zone on the bed elevation discordance between the tributary channel and the main channel. Schindfessel et al., (2015) [10] used a large eddy simulation to study the flow patterns in three dimensions for the three different discharge ratios.

The problem in this paper has not been posed previously by researchers. It refers to the impact of the bed flume uniformity discordance on the hydraulic characteristics of the weir-gate structure. A few researchers dealt with weir-gate structures, considering that the channel bed is either horizontal or sloping. However, they did not assess the effect of bed discordance. Alhamid et al. (1996) [11] predicted the discharge quantity over the rectangular weirs and below the triangular gates. From their prediction, they obtained an equation including all the significant variables that were obtained from the experimental investigation. This equation is appropriate for both sloping and horizontal channel beds under free and submerged flow conditions, respectively. Further, Alhamid et al. (1997) [12] carried out experiments to minimize the state of sediment.

In this study, a combined structure of triangular weir and rectangular gate was suggested and studied experimentally. The experiments were carried out for free flow conditions for both sloping and horizontal channels. Negm et al. (2001) [13] used the experimental results to develop and predict the equation to estimate the flow that crosses the combined weir-gate structure under the free flow condition. It is found that only one equation is reasonable for both sloping and horizontal channels with either steep or mild sides.

Qasim et al (2020) [14] examined experimentally the effect of the inclination angle of the weir-gate structure on the hydraulic behavior of the discharge structure. The research deals with different inclination angle values. Several hydraulic parameters which dominate the discharge structure are also being studied. Qasim et al. (2020) [15] tried to carry out many experiments in order to investigate the impact of the submerged obstacles with the opening and without the opening on the hydraulic response of the weir-gate structure. From the results, it is found that the obstacles have a major impact on the flow pattern of the discharge structure. It is also found that any change in the hydraulic behavior of the discharge structure will be attributed to the existence of the obstacles in the downstream zone. In this connection, various hydraulics variables and dimensions variables are considered in the study. Qasim et al., (2020) [16] tried to conduct many experiments to reveal the impact of the submerged barriers on the hydraulic response of the combined weir-gate hydraulic structure. From the results, it is found that the barriers have a major influence on the hydraulic variables of the discharge structure. Also, it is found that any change in the hydraulic response of the discharge structure will be attributed to the altered barriers' location, spacing, and numbers. In addition, Qasim et al. (2021) [17] tried to perform other experiments to investigate the influence of the square submerged obstacles on the hydraulic response of the weir-gate structure. The results show that the obstacles have a major impact on the hydraulic variables of the discharge structure. It is found that any change in the hydraulic behavior of the discharge structure will be attributed to the existence of the square submerged obstacles.

Abdulhussein et al. (2022) [18] investigated experimentally and statistically the effect of the longitudinal obstacle on the hydraulic response of the discharge structure. The effect of obstacle length and the obstacle cross-sectional area are considered in the study. The longitudinal obstacle has a moderate impact on the hydraulic characteristics of the discharge structure. Abdulhussein et al. (2022) [19] examined experimentally the hydraulic interference between the obstacle dimensions and the hydraulic parameters that controlled the discharge structure. As well, the optimization analysis is used to compute the obstacle optimal dimension. Abdulhussein et al. (2022) [20] based on the experimental data, derived a general equations to predict the discharge which passes through the discharge structure. The formulas are applied for free flow conditions only. Various shapes of weirs and gates are employed to implement the experiments in order to obtain the required data.

The aim of the current study is to reveal experimentally the influence of the bed flume discordance on the weir-gate hydraulic structure, namely, the impacts on the flow characteristics, the relationship between the weir-gate structure and the discordance of the bed, and the downstream water depth. Ultimately, the effect of the discordance on the flow depth and on the specific energy was investigated. Also, a comparison between the discordance and concordance of bed flume is made. Here, the discordance along the flume (trough).

2. Fluid Fundamental

The discharge quantity which passes through the weir-gate structure can be estimated according to the procedure which is shown below. The experimental run deals with three different shapes of weir. Here, the gate has a non-regular shape while the weir has both a regular shape and a non-regular shape. Below, the procedure for the discharge quantity estimation has been reviewed.

For triangular weir [21]:

$$Q_w = 8/15\sqrt{2g}\ \tan\emptyset/2\ {h_u}^{5/2} \tag{1}$$

For rectangular weir [21]:

$$Q_w = 2/3\sqrt{2g}\ b{h_u}^{3/2} \tag{2}$$

For Parabolic weir [22]:

$$Q_w = \pi/2\sqrt{fg}{h_u}^2 \tag{3}$$

For gate: The theoretical discharge that passes the gate can be calculated from:

$$Q_g = VA = \sqrt{2gH}\ A \tag{4}$$

From Equation 4, it is obvious that the theoretical flow velocity represents a function of the flume upstream water depth [23, 24]. For free flow condition:

$$H = d + y + h_u \tag{5}$$

For submerged flow condition:

$$H = d + y + h_u - h_d \tag{6}$$

For weir-gate composite hydraulic structure: The theoretical and actual discharge can be calculated according to:

$$Q_{theor} = Q_w + Q_g \tag{7}$$

$$Q_{act} = c_d\ Q_{theo} \tag{8}$$

$$Q_{act} = c_d\left[Q_w + Q_g\right] \tag{9}$$

where H is upstream water depth, h_u is weir water head, y is vertical distance between weir and gate, d is gate opening height, A is gate cross-section flow area, V is flow velocity, f is focal distance, b is rectangular weir width, θ is notch angle, g is acceleration due to gravity, Q_w is weir discharge, Q_a is gate discharge, Q_{theor} is theoretical discharge, Q_{act} is actual discharge, c_d is coefficient of discharge.

$$R_e = \frac{VL}{\nu} \tag{10}$$

$$F_r = \frac{V}{\sqrt{gh}} \tag{11}$$

where, R_e is Reynold's number, F_r is Froude number, ν is the kinematic viscosity of water, L: characteristic length and equal to the hydraulic radius (R), and h: water depth.

$$R = \frac{A}{P} \tag{12}$$

where A is the water area and P is the wetted perimeter.

The specific energy (specific head) of a channel with rectangular section is estimated from the following equation [25]:

$$E = h + \frac{q^2}{2gh^2} \tag{13}$$

$$q = \frac{Q}{b} \tag{14}$$

where q is the discharge per unit width, Q is the discharge and b is the channel width.

The percentage of the increase or the decrease in the downstream water depth can be calculated as in:

$$H_d\% = \frac{(H_d)_{case} - (H_d)_{case-5}}{(H_d)_{case-5}} \tag{15}$$

Where, case may be case1, case2, case3 or case4

The main parameters that have a direct influence on the hydraulic behaviour of the weir-gate structure are those that are considered in the experiments, hydraulic analysis, and statistical analysis illustrated in Table 4 (Section 4). Commonly, these parameters are used to describe the hydraulic characteristics of weir-gate structures under free flow and submerged flow.

3. Experiment Setup

The experimental runs in this investigation are performed in an experimental flume 15cm deep, 7.5cm wide and 200cm long with a glass side-wall. A weir-gate hydraulic structure is installed inside the flume. This investigation also deals with weirs that have regular and non-regular shapes with different geometrical dimensions, while the gate has a non-regular shape with different geometrical dimensions. The weir, which is adopted in this study, has a rectangular, triangular, and parabolic shape, respectively, while the gate has a half-ellipse shape. The parabolic weir has the form $Y=X^2$. In these experiments, the investigation concentrated on the influence of discordance in the horizontal bed of the flume on the hydraulic response of the weir-gate structure and the response of the hydraulic regime downstream of the flume. The volume method is utilized to measure the actual discharge. The water depth at the downstream of the flume is measured by using a scale fixed to the wall of the flume. This investigation includes the measurement of upstream water depth and water depth above the weir crest. Here, the weir-gate structure was made of wood sheet 5 mm thick, beveled along all the edges at 45 degrees with sharp edges of 1 mm. The weir-gate was fixed to the flume using Plexiglas supports. Figure 1 illustrates the shapes of different weir-gate structures, while Figure 2 illustrates the entire whole hydraulic system. In addition, Figure 2 shows the discordance in the horizontal bed flume and weir-gate structure. Table 1 illustrates the details of the weir-gate hydraulic structure and water depth measurement upstream of the weir-gate hydraulic structure, respectively. In this study, the discordance along the flume (trough) is considered for a specified length at the downstream of the flume. Figure 3 shows the flowchart of all experiments and hydraulic calculations in addition to statistical analysis.

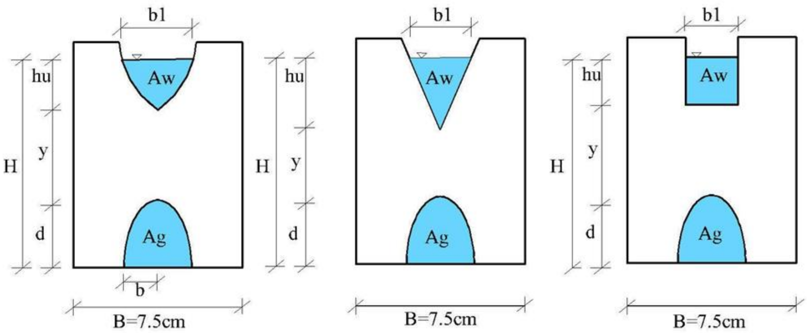

Figure 1. The details of weir-gate structure

Table 1. The details of weir-gate structure models

Model No.	Weir Shape	Gate shape	h_u (cm)	y (cm)	d (cm)	H (cm)	y/H	$A_g\ (cm^2)$	A_g/BH
1--1	Rectangular	Ellipse	1	4.5	2.5	8	0.5625	4.908	0.0818
1--2	Rectangular	Ellipse	2	4.5	2.5	9	0.5000	4.908	0.0727
1--3	Rectangular	Ellipse	3	4.5	2.5	10	0.4500	4.908	0.0654
2--1	Triangular	Ellipse	1	3.5	2.5	7	0.5000	4.909	0.0935
2--2	Triangular	Ellipse	2	3.5	2.5	8	0.4375	4.909	0.0818
2--3	Triangular	Ellipse	3	3.5	2.5	9	0.3889	4.909	0.0727
3--1	Rectangular	Ellipse	1	4	3	8	0.5000	7.068	0.1178
3--2	Rectangular	Ellipse	2	4	3	9	0.4444	7.068	0.1047
3--3	Rectangular	Ellipse	3	4	3	10	0.4000	7.068	0.0942
4--1	Parabolic	Ellipse	1	4.5	2.5	8	0.5625	4.908	0.0818
4--2	Parabolic	Ellipse	2	4.5	2.5	9	0.5000	4.908	0.0727
4--3	Parabolic	Ellipse	3	4.5	2.5	10	0.4500	4.908	0.0654
5--1	Triangular	Ellipse	1	3	3	7	0.4286	7.069	0.1346
5--2	Triangular	Ellipse	2	3	3	8	0.3750	7.069	0.1178
5--3	Triangular	Ellipse	3	3	3	9	0.3333	7.069	0.1047
5--4	Triangular	Ellipse	4	3	3	10	0.3000	7.069	0.0942
6--1	Parabolic	Ellipse	1	4	3	8	0.5000	7.068	0.1178
6--2	Parabolic	Ellipse	2	4	3	9	0.4444	7.068	0.1047
6--3	Parabolic	Ellipse	3	4	3	10	0.4000	7.068	0.0942

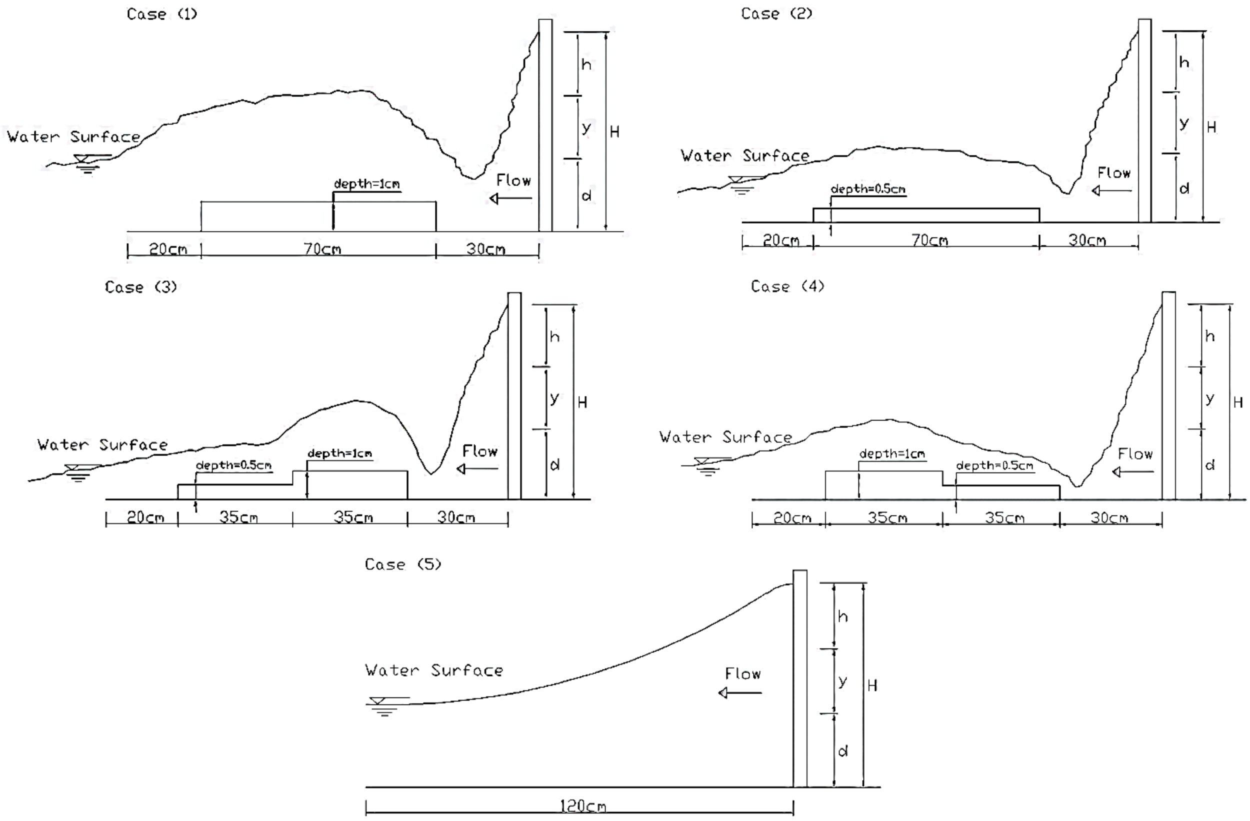

Figure 2. The discordance in horizontal bed flume and weir-gate structure

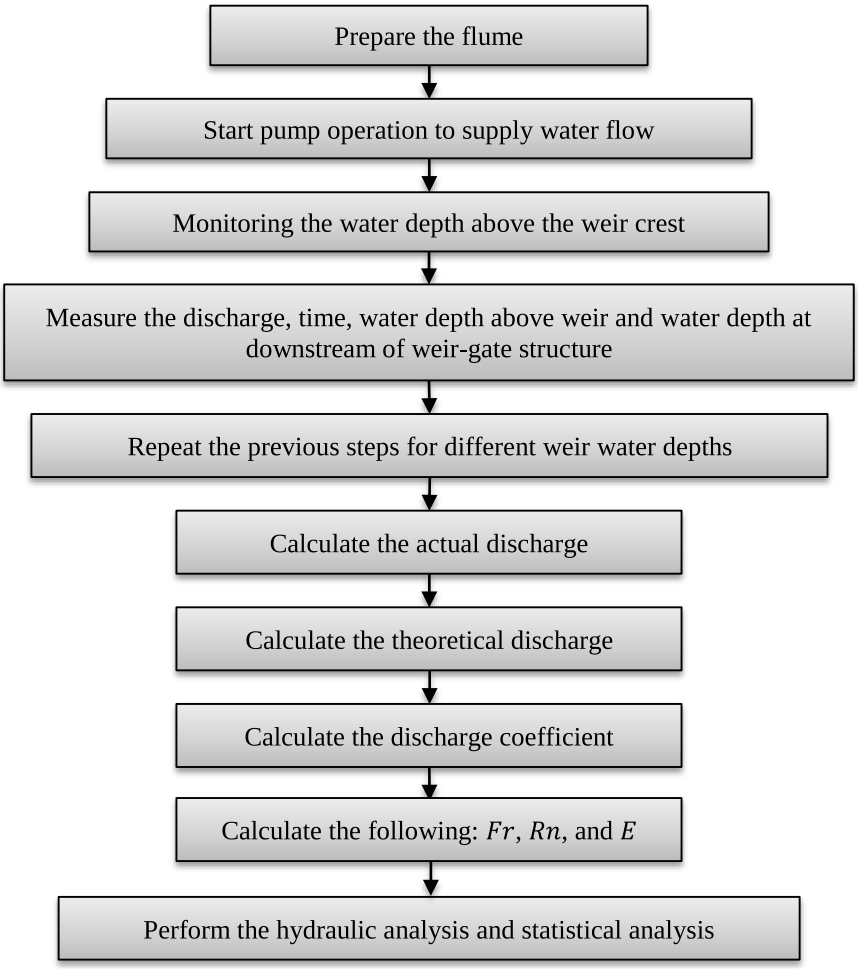

Figure 3. Flowchart of experiments, hydraulic analysis and statistical analysis

3.1. Statistical Analysis

Two-way ANOVA were used to investigate the relationship between dependent hydraulic characteristics (hd/H and Q/gH) and independent hydraulic characteristics (Ag/HB, y/H, Re, Fr_{up}, and Fr_{down}). All statistical analysis was performed using the software package IBMSPSS 24.

4. Results and Discussions

A weir-gate hydraulic structure was popularly used in irrigation engineering work, so it is important to investigate the interaction happening between this hydraulic structure and the open channel (flume) bed discordance and concordance owing to the significant interaction shown between the hydraulic variables under the bed discordance, which effects on the response of the hydraulic regime. Figure 4 illustrates the variation in trend between the water depth ratio and the downstream Froude number. The different bed flume discordance configurations (cases 1, 2, 3, and 4) compared with the concordance in the bed flume configuration (case 5) are considered. The water depth ratio here represents the ratio of average downstream water depths to upstream water depths. The current study shows that both water depths will change. In general, the Froude number is affected by water velocity and depth, implying a complex trend in the hydraulic relationship.

For all cases, Figure 4 indicates that as the water depth ratio increases, the Froude number tends to decrease. This case occurs owing to the inverse proportion between the Froude number and water depth. Moreover, this figure illustrates that the discordance effect is more visible, especially in case-3, owing to the discordance height in the bed flume, which is reflected in the flow depth and dominates the values of Froude number at downstream of the hydraulic regime. Over all, as the discordance height increases, the water depth will be decreased, and this state will be reflected in the values of the Froude number. Cases 1, 2 and 4 imply that the discordance has a moderate and reasonable impact on the trend between the Froude number and the water ratio. Also, Figure 4 shows a significant interaction between the cases: 1, 2, and 4 regardless of the height of the bed flume discordance. Generally, the assessment of the discordance can be described as strong for case 3 and reasonable for cases 1, 2, and 4 as compared with the concordance case 5, as it is clear that case 5 has moderate hydraulic behaviour.

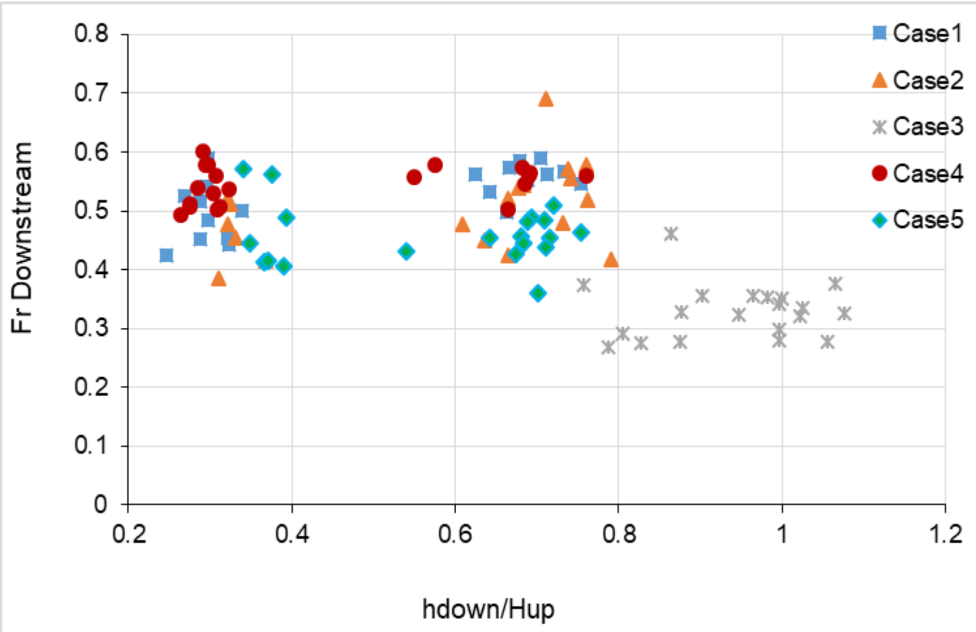

Figure 4. Relation between downstream Froude number and water depth ratio *h-downstream/H-upstream*

Figure 5 illustrates the variation in relationship found between the Froude number at downstream and the ratio $h_{downstream}/y$, where y represents the vertical distance between the weir and gate. From this figure, for all cases, it is clear that the increase in the ratio $h_{downstream}/y$ leads to the slight increase in the Froude number values. In general, the Froude number depends on the flow velocity and flow depth. The Froude number is directly proportional to flow velocity and inversely proportional to flow depth. From Figure 5, the increase in the Froude number will be attributed to the alteration in the flow velocity; furthermore, the flow velocity has a major influence on the Froude number as compared with the flow depth. Figure 5 indicates the composite effect of the overlapping between weir flow velocity, the gate flow velocity, and the effect of the discordance in the bed flume. Both effects will be shared in the variation of the obtained results. At this point, it is clear that case 5 has moderate hydraulic behavior.

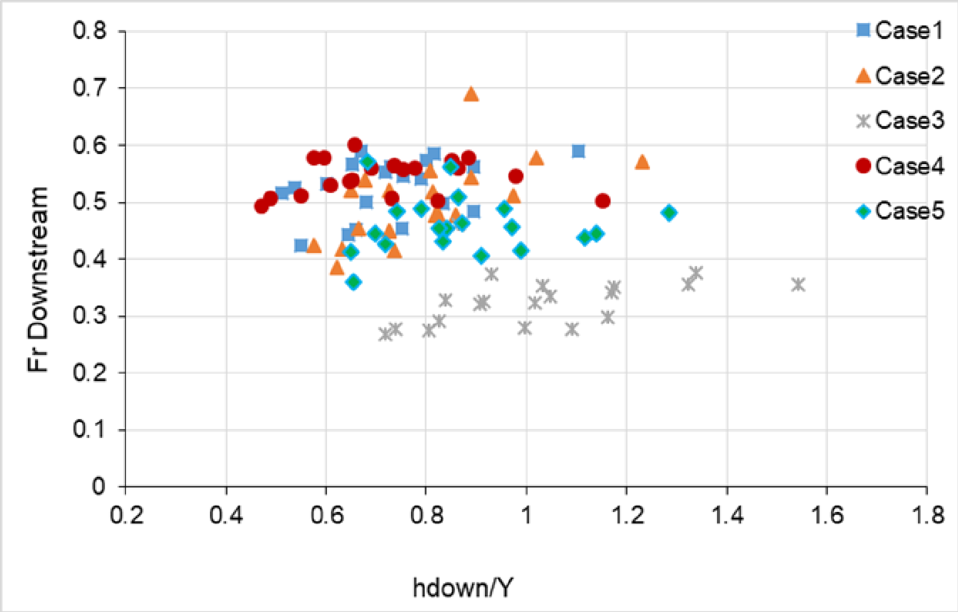

Figure 5. Relation between downstream Froude number and *h-downstream/y*

Figure 6 depicts the relationship between the downstream Froude number and the ratio $h_{downstream}$ / L_{down}. In fact, the contrast in Froude number depends on flow velocity and flow depth. Here, the water depth has a major impact on the distribution of the Froude number values at the downstream of the hydraulic regime. This happens owing to the inverse proportionality between the water depth and Froude number.

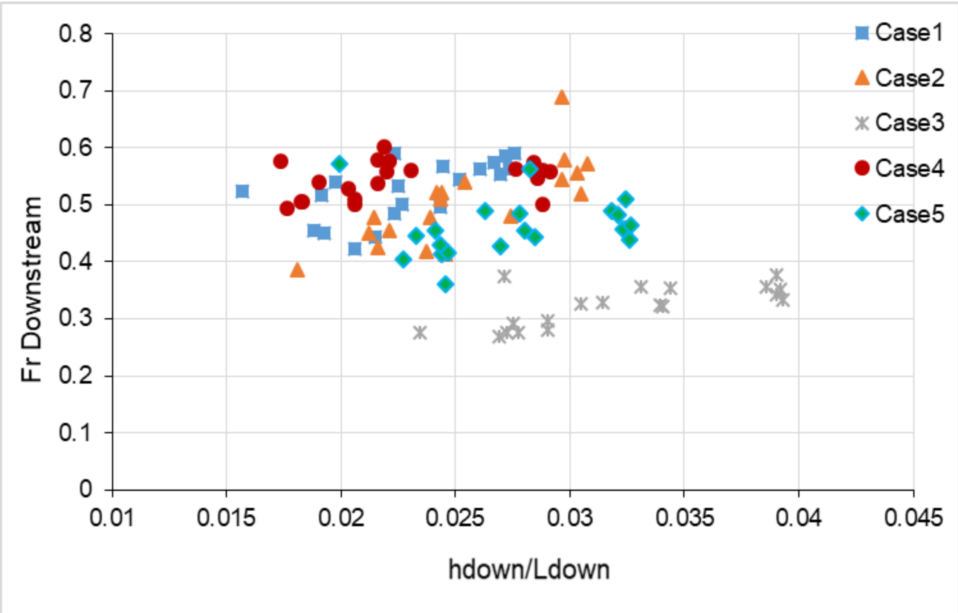

Figure 6. Relation between downstream Froude number and *h_downstream/L_down*

For all cases except case 5, it is obvious from the figure that the complex trends in the relationship between the hydraulic variables and the inequality in value distribution are attributed to the vital role of the bed flume discordance.

The discordance leads to the change in the depth of water from section to section and becomes relevant along the path of downstream. In addition, the discordance will be reflected on the flow velocity, which results from the interaction between the overflow velocity and the underflow velocity. Case 5 (concordance case) has approximately the same hydraulic trend as the other cases. The interaction between overflow velocity and underflow velocity leads to the variation in the relation between the hydraulic variables. In addition, case 5 has moderate hydraulic behavior.

Figure 7 is designed to express the variation between downstream Froude number and the ratio of $h_{downstream}$ / $L_{concordance\ length}$. For all cases, it is obvious that as the Froude number increases, the water depth increases too, regardless of the inverse proportion between them. In this situation, the increase in flow velocity has more influence on Froude number as compared with the increase in flow depth. This happens owing to the direct proportion between the flow velocity and Froude number. As a result, any increase in flow velocity is reflected positively despite the increase in flow depth. Consequently, the fluctuation in the results appears owing to the interaction between overflow velocity and underflow velocity. This interference with discordance supports the fluctuation strongly. Figure 8 shows an important relation between downstream Froude number and $h_{downstream}$ / $L_{concordance\ length}$ and a complicated trend in the relation found between the hydraulic variables. This complexity results from the drastic alteration in flow velocity owing to the sudden encounter between the water path and the bed flume discordance. This means that the variation in the bed flume elevation (discordance) will be reflected in the water depth and the water flow velocity. In this condition, Froude number values would be influenced by the downstream discordance elevation, which affects the flow depth at that zone, so the water depth will be dominant in the determination of the Froude number values at that zone.

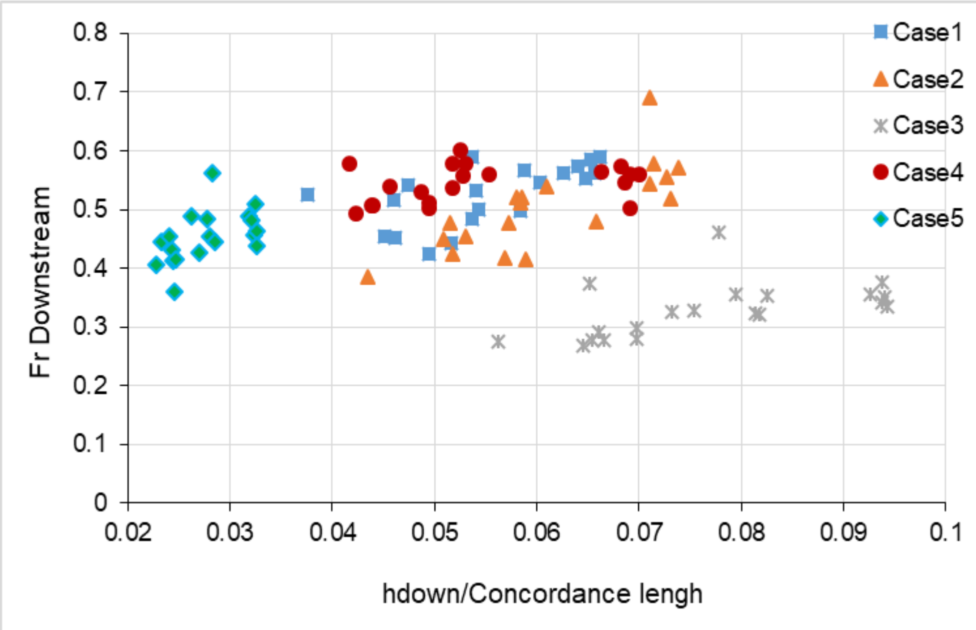

Figure 7. Relation between downstream Froude number and *h_downstream/(concordance length)*

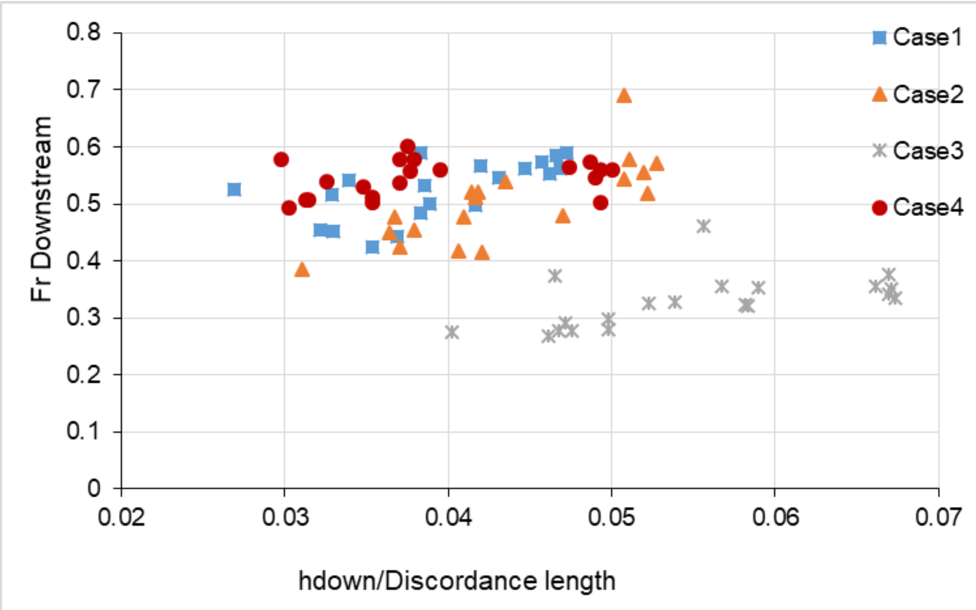

Figure 8. Relation between downstream Froude number and *h_downstream/(Discordance length)*

Moreover, the flow velocity will be affected by the bed flume discordance and this too will be reflected in the Froude number values. Figure 8 implies that all cases have approximately the same hydraulic behaviour regardless of the discordance configuration. Figure 9 shows the trend in the relationship that existed between the actual discharge and the flow velocity. This figure refers to a noticeable trend. In the sense that any rise in discharge quantity would be associated with a rise in the flow velocity because of the direct proportion between them according to the continuity equation regardless of the type of case.

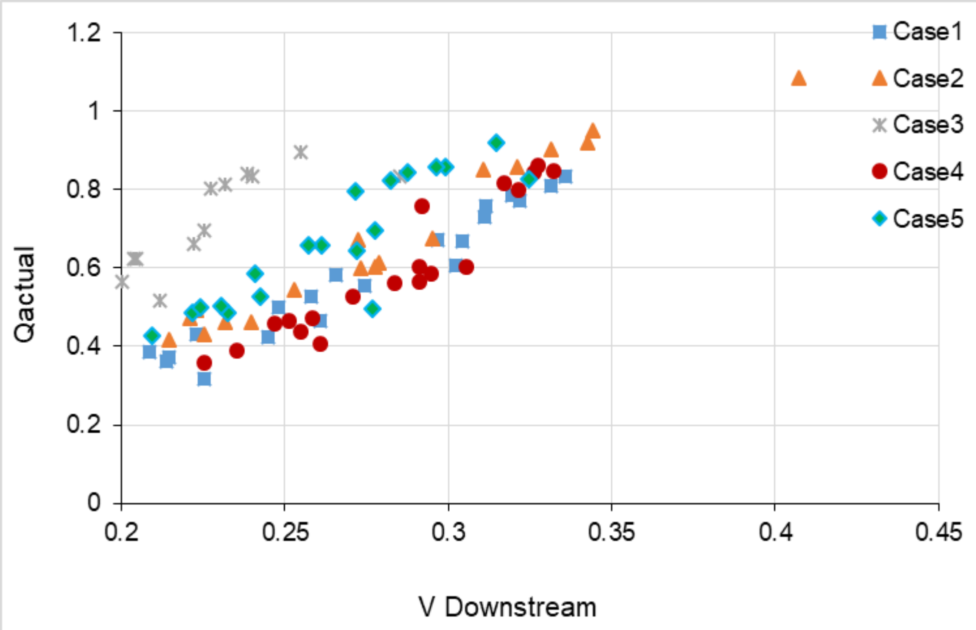

Figure 9. Relation between actual discharge and downstream flow velocity

Figure 10 shows the trend in relation between discharge coefficient and downstream Froude number. There is no empirical or theoretical relation between the discharge coefficient of a weir-gate structure and Froude number, so both of them can be considered independent non-dimensional hydraulic variables. Here, it is very important to mention that the discharge coefficient is based on hydraulic characteristics and geometrical dimensions of the weir-gate structure, while the Froude number at the downstream regime is based on water depth and flow velocity at the downstream, so there is no overlapping between the non-dimensional variables. Therefore, Figure 10 produces a dramatic, complex, random relationship regardless of the impact of the discordance and concordance.

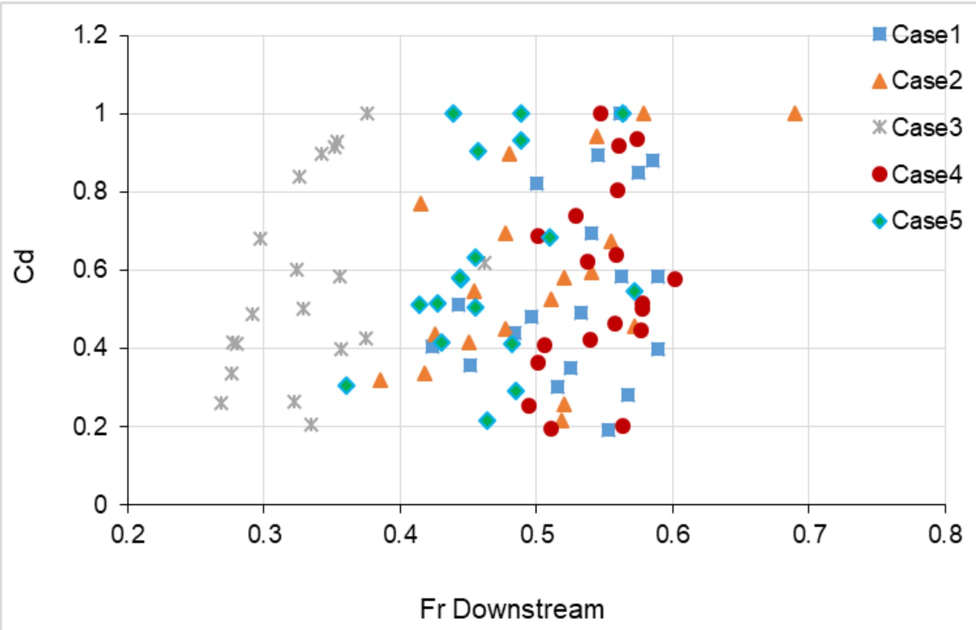

Figure 10. Relation between discharge coefficient and Froude number at downstream

Figure 11 introduces a strong relation between Reynolds number and Froude number in the downstream regime. It is clear from the figure that any increases or decreases in the Froude number would reflect on the Reynolds number. This occurs owing to both of them depend on flow velocity; at the same time, both of them have direct proportional with flow velocity. It is obvious that discordance and concordance have the same effect on the relationship and the results.

Figure 12 shows the trend between the ratio Ag/B.H and the Froude number at downstream, where B represents the width of the water surface at upstream. When the cross section area of flow passes the gate increases, this means the increase occurs either in water depth or/and water width at the downstream of the hydraulic regime.

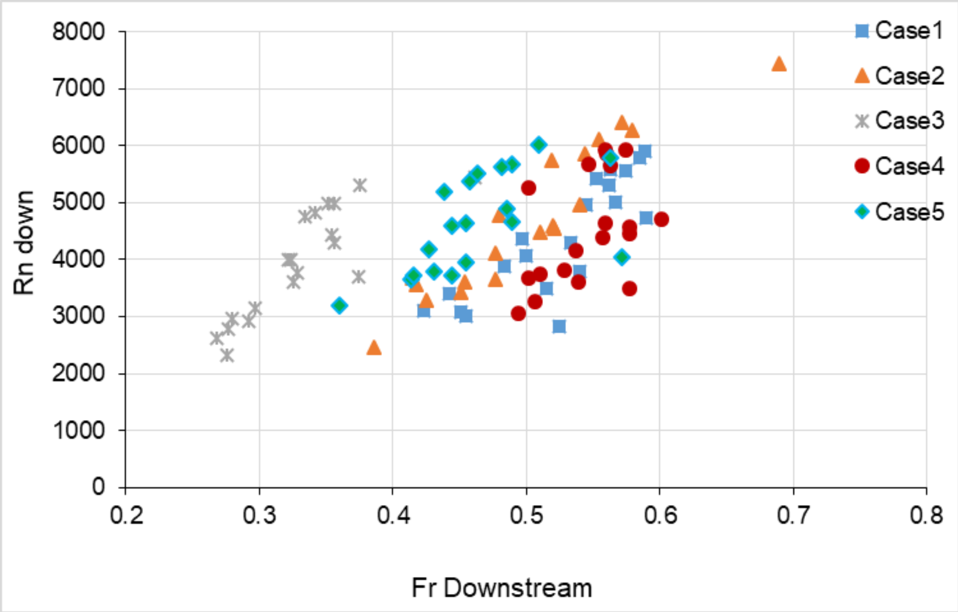

Figure 11. Relation between Reynolds number and Froude number at downstream

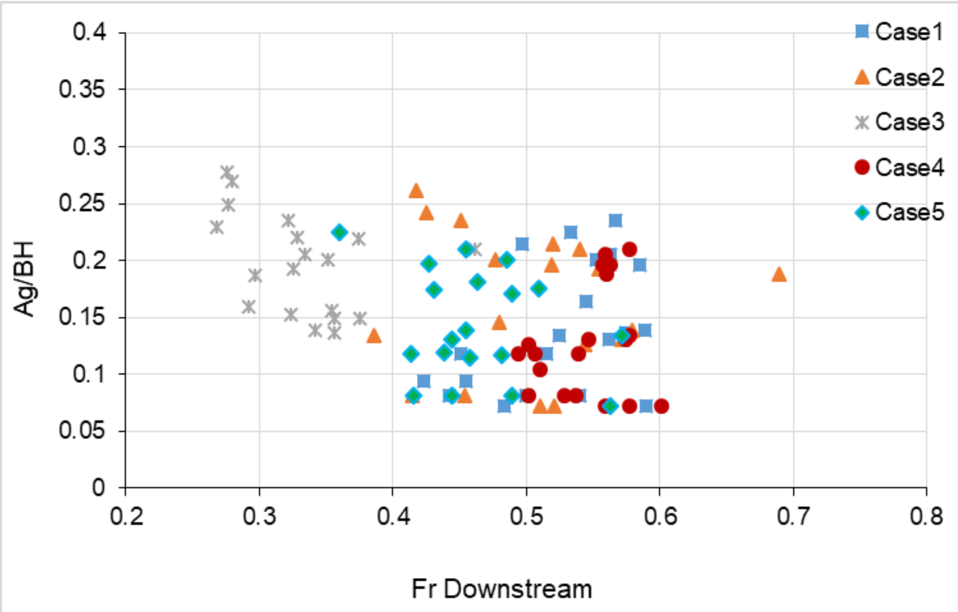

Figure 12. Relation between *Ag/BH* and downstream Froude number

In the present study, the water width is considered constant, therefore, the increases in flow water area leads to an increase in water depth. Basically, any increase in water depth leads to a decrease in Froude number owing to the inverse proportional between them. This condition is applicable for all cases except for case-1 and case-5. In case-1, the effect of discordance is appears sharply on the water depth. The height of discordance reduces the flow depth and this would effect on the Froude number. While in case-5 the interaction between overflow velocity and underflow velocity leads to the variation in the distribution of values. The relation between the specific energy and the average water depth at downstream is shown in Figure 13. It is obvious from the figure that as the water depth increases, the specific energy will increase too, regardless of the discordance and concordance cases, respectively.

Generally, the specific energy depends on the water depth. The relationship between specific energy and flow velocity at a downstream is shown in Figure 14. It is obvious from the figure that as the flow velocity increases, the specific energy would increase too, regardless of the discordance and concordance cases, respectively. Generally, the specific energy depends on the flow rate per unit width. In this study, the width is considered constant, so any increase in flow rate leads to an increase in flow velocity owing to the direct proportional between them according to the continuity equation. Therefore, any increase in flow velocity would have an effect on the specific energy. Table 2 includes some statistical calculations for the present experimental study, which are related to the actual discharge, average downstream water depth, and the discharge coefficient, respectively.

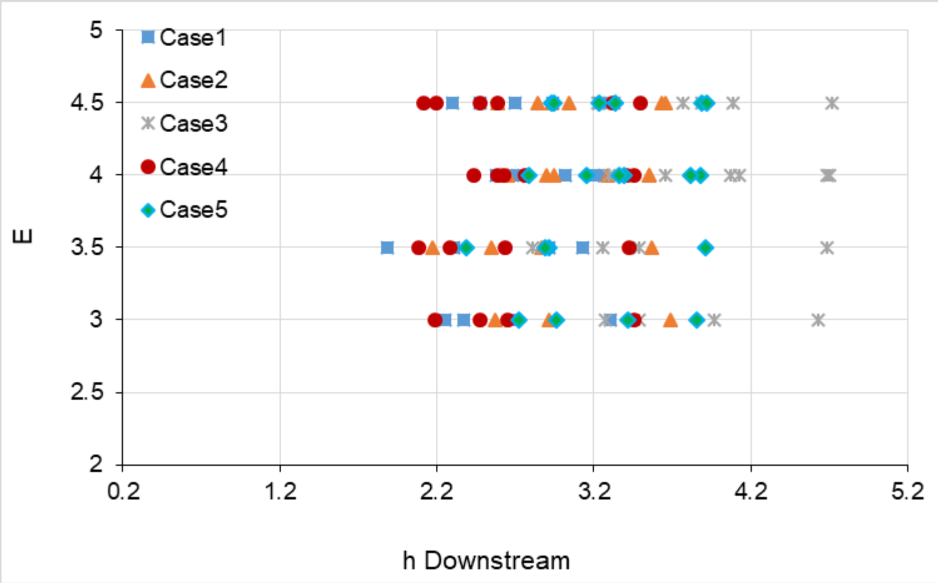

Figure 13. The relation between specific energy and average water depth at downstream

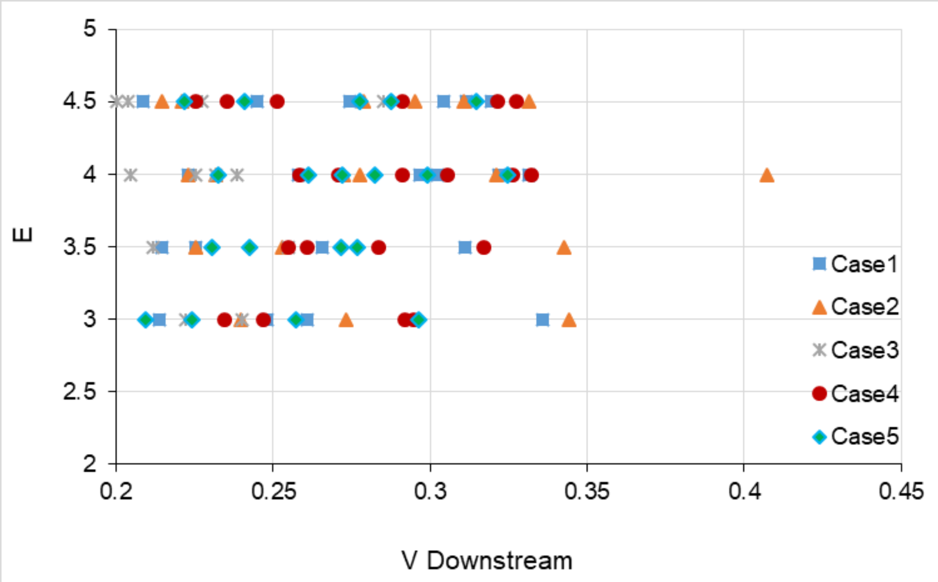

Figure 14. The relation between specific energy and flow velocity at downstream

Table 2. Statistical data of the experimental study

Case	Variable	Mean	Median	Sta. Deviation	Sample variance	Max.	Min.
Case 1	Q_{act}	0.5779	0.5687	0.1635	0.0267	0.8333	0.3181
	h_d	2.7623	2.7091	0.4018	0.1614	3.3091	1.8818
	C_d	0.5573	0.4907	0.2394	0.0573	1.0684	0.1921
Case 2	Q_{act}	0.6373	0.6010	0.2140	0.0458	1.0856	0.2901
	h_d	3.0493	2.9273	0.4426	0.1959	3.6909	2.1727
	C_d	0.6120	0.5461	0.2957	0.0874	1.3442	0.2163
Case 3	Q_{act}	0.5997	0.5955	0.1850	0.0342	0.8955	0.3061
	h_d	3.8581	3.8312	0.5787	0.3349	4.7143	2.8143
	C_d	0.5828	0.4999	0.2787	0.0777	1.3108	0.2042
Case 4	Q_{act}	0.5871	0.5632	0.1692	0.0286	0.8596	0.3580
	h_d	2.7341	2.6091	0.4892	0.2393	3.5000	2.0818
	C_d	0.5729	0.5166	0.2561	0.0656	1.1932	0.1964
Case 5	Q_{act}	0.6509	0.6516	0.1611	0.0259	0.9184	0.4280
	h_d	3.2864	3.2864	0.4566	0.2085	3.9182	2.3909
	C_d	0.6339	0.5762	0.2688	0.0723	1.1658	0.2147

The statistical calculation gives very close values for the median and the mean. This means that the measured experimental data is distributed symmetrically or in a balanced distribution. Also, the table includes the standard deviation, sample variance, maximum, and minimum.

Table 3 shows the percentage increase or decrease in average downstream water depth. The effect of the non-uniformity in the bed flume is obvious, and this will be reflected in the water depth. Furthermore, case (3) gives the highest positive percentage of increase in the water depth as compared with other cases.

Table 3. Average downstream water depth percentage of increase or decrease

Run NO.	h_d% - case1	h_d% - case2	h_d% - case3	h_d% - case4
1	-0.1565	-0.0654	0.0000	-0.1005
2	-0.1657	-0.0590	0.1653	-0.1994
3	-0.1553	-0.1149	0.1371	-0.2484
4	-0.1756	-0.0843	0.2071	-0.1218
5	-0.1099	-0.0295	0.2175	-0.1850
6	-0.1383	-0.0663	0.1593	-0.2277
7	-0.1740	-0.0673	0.2032	-0.1531
8	-0.1199	-0.1226	0.2246	-0.2589
9	-0.2191	-0.0340	0.0961	-0.2809
10	-0.1452	-0.0690	0.2310	-0.0952
11	-0.2027	-0.1378	0.2104	-0.2189
12	-0.0749	-0.0489	0.1824	-0.0717
13	-0.2000	-0.0860	0.1987	-0.1233
14	0.0000	-0.0187	0.1162	-0.0966
15	-0.2013	-0.1195	0.2058	-0.2107
16	-0.2129	-0.0913	0.1771	-0.1293
17	-0.1415	-0.0425	0.2008	-0.1038
18	-0.2154	-0.1463	0.1619	-0.2234
19	-0.1994	-0.1319	0.1762	-0.1656

It is very important to measure the variance of the hydraulic characteristics, which is described by the weir-gate hydraulic structure, owing to the existence of the discordance and the concordance. For this purpose, ANOVA is employed to investigate the variance in the hydraulic characteristics. Table 4 deals with the influence of the ratio h_d/H and the ratio Q/g.H on the following Ag/H.B, y/H, R_e, Fr_{up}, and Fr_{down}. Here, we have two groups, the first group refers to the dependent variables, which are expressed as the ratio h_d/H and the ratio Q/g.H, while the second group refers to the independent variables, which are expressed as Ag/H.B, y/H, R_e, Fr_{up}, and Fr_{down}. Table 4 includes the following parameters: sum of square, degree of freedom (df), mean square, F-statistic, and significant level (sig.). Where F-statistic is refer to the variation between sample means divided by the variation with in the sample. The F-test can be used to assess the equality and inequality of the variance, so the F-test has become a very important and flexible test. The F-test is used to find whether the group means are equal.

The F-test depends on the null hypothesis. The null hypothesis may be true or false. If the null hypothesis is considered true, the F-ratio is equal to or close to one and there is no group difference, but if the null hypothesis is considered false, then the F-ratio is larger than one or less than one and there is a group difference. So it is noticed that Table 4 reveals the effect of the group dependent variables on the one independent variable as compared with the effect of a single dependent variable on the same independent variable. In general, a significance level of 0.05 works well. A significance level of 0.05 refers to a 5% risk of the conclusion that a difference exists when there is no actual difference. Table 4 clarifies a good significance level except that the significance of the Reynolds number and Froude number at downstream is considered not to have a significant level as compared with the remaining parameters.

Table 4. Analysis of the independent hydraulic characteristics (h_d/H and Q/gH) and dependent hydraulic characteristics (Ag/HB, y/H, R_e, Fr_{up} and Fr_{down}) respectively by ANOVA

		Sum of Squares	df	Mean Square	F	Sig.
hd/H	Between Groups	11.953	75	0.159	14.837	0.023
	Within Groups	0.032	3	0.011		
	Total	11.985	78			
Q /gH	Between Groups	9.801	75	0.131	12.837	0.028
	Within Groups	.031	3	0.010		
	Total	9.831	78			
hd/H	Between Groups	11.817	60	0.197	21.088	0.0001
	Within Groups	0.168	18	0.009		
	Total	11.985	78			
Q /gH	Between Groups	9.573	60	0.160	11.101	0.0001
	Within Groups	0.259	18	0.014		
	Total	9.831	78			
hd/H	Between Groups	11.472	74	0.155	1.209	0.488
	Within Groups	0.513	4	0.128		
	Total	11.985	78			
Q /gH	Between Groups	9.728	74	0.131	5.073	0.061
	Within Groups	0.104	4	0.026		
	Total	9.831	78			
hd/H	Between Groups	11.969	73	0.164	51.071	0.0001
	Within Groups	0.016	5	0.003		
	Total	11.985	78			
Q /gH	Between Groups	9.831	73	0.135	110995711	0.0001
	Within Groups	0.000	5	0.000		
	Total	9.831	78			
hd/H	Between Groups	10.948	72	0.152	0.880	0.650
	Within Groups	1.037	6	0.173		
	Total	11.985	78			
Q /gH	Between Groups	9.179	72	0.127	1.174	0.466
	Within Groups	0.652	6	0.109		
	Total	9.831	78			

5. Conclusion

An experimental study has been performed in order to evaluate the influence of the bed flume discordance on the hydraulic characteristics of the weir-gate structure in a flume. Different bed flume discordance configurations are adopted in the experiment investigation. It is found that the variation in longitudinal bed flume elevation would cause a deviation in the hydraulic characteristics of the weir-gate structure, while reasonable hydraulic behavior is obtained in the concordance case, as compared with noticeable and dramatic hydraulic behavior in the discordance case. The increase in both water depth and flow velocity at the downstream regime of the weir-gate structure significantly contributes to an important rise in specific energy. The change in the bed flume configuration has a remarkable impact on the water surface path. Consequently, the water path over the bed flume concordance region differs as compared with the bed flume discordance region. In addition, this point is visible clearly in all experiments. It has been observed that, regardless of bed flume concordance and discordance, some cases of similarity in hydraulic behavior may occur.

The magnitude of the average water depth at the downstream would be more influenced by the upstream water depth and the vertical distance between weir and gate. At the downstream of the weir-gate hydraulic structure, the Froude number values change with the length of the downstream regime due to the non-uniformity in the bed flume. The result illustrate a direct relationship between Froude number and Reynolds number at downstream regime of weir-gate structure. Besides, a direct relationship between the actual discharge and flow velocity, is flourished at downstream, while a complicated relationship will be seen between the discharge coefficient of weir-gate structure and Froude number at downstream regime. It was shown that the cross sectional area of flow which passes the gate has a vital role in dominating the values of Froude number in the downstream regime. Also, the following major notice has been inferred from the hydraulic analysis: The interaction between overflow velocity and underflow velocity has a major impact on the hydraulic characteristics. It is evident that the height of the discordance will have an effect on the water depth, and this will ultimately lead to a rise or drop in the water level at that zone. As well, the bed flume non-uniformity or bed flume discordance will be worked as an obstacle in the downstream zone of the flume.

6. Declarations

6.1. Author Contributions

Conceptualization, R.M.Q.; methodology, R.M.Q., A.A.M. and I.A.A.; software, A.A.M.; validation, R.M.Q., A.A.M., and I.A.A.; formal analysis, R.M.Q.; investigation, R.M.Q. and I.A.A.; resources, R.M.Q., A.A.M., and I.A.A.; data curation, I.A.A.; writing—original draft preparation, R.M.Q.; writing—review and editing, A.A.M.; visualization, R.M.Q.; supervision, I.A.A.; project administration, I.A.A. All authors have read and agreed to the published version of the manuscript.

6.2. Data Availability Statement

The data presented in this study are available in the article.

6.3. Funding

The authors received no financial support for the research, authorship, and/or publication of this article.

6.4. Ethical Approval

Not applicable.

6.5. Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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