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Performance of Flow Through and Over Trapezoidal Gabion Weir

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Abstract

Different upstream and downstream slopes of trapezoidal gabion were studied in open laboratory flume. The upstream flow depth and the discharge were investigated through laboratory experiments. Twelves models were tested in a laboratory flume. The experiment tests included three regimes of flow (Through flow, Transition Flow, and Overflow) under free flow conditions. The trapezoidal slopes were changed three times (1:1, 1:1.5, and 1:2). For each trapezoidal slope, gravel coarseness differed four degrees (1.13, 1.58, 2.19, and 2.27 cm). The analysis of experimental results showed that as material coarseness increased, the discharge pass through trapezoidal gabion weir increased from 17.5%. to 35.8%. All models showed that discharge (Q) is related to the ratios of upstream height of water to length of weir (H/L) and the percentage of discharge is increase from 16% to 50% due to change side slopes from 1:1 to 1:2.The discharge coefficient is related to the (H/L , H/p and dm/H).The discharge coefficient increased with the increase in gravel coarseness (porosity) and increase the side slops from (1:1 to 1:2) also cause the coefficient of discharge increase. Two mathematical models for the water flow depth and the coefficient of discharge predicted for the three flow regimes are presented. The estimated and computed values showed a high degree of correlation.

Keywords: Porose weir, Gabion, Coefficient of Discharge, Trapezoidal weir, Free flow.

Introduction

Weirs are engineering structures used to regulate, control, and redirect water from the flow pathway. They are always built orthogonal to the flow pathway. A weir usually consists of impermeable materials, and for this type, the flow is limited to passing over the crest only. But instead of impermeable constructions, permeable weirs which allow water to pass through the body structure are being considered more often these days. The gabion weir is a form of permeable weir with several advantages compared with a solid weir. It is cost-effective and durable to lessen the effects of flooding. Gabions stepped weir helps energy dissipation in waterway.

Several physical models were tested to calculate the discharge coefficients for rectangular broad-crested gabion weirs. To determine the best parameters to control the flow, dimensional analysis was done and the outcome showed that the coefficient of discharge of gabion weirs is higher than solid weirs [1]. As the discharge increases, so does the hydraulic jump distance. However, the hydraulic jump distance is affected unevenly by changing the values of the gravel sample utilized and the weir's overall length. [2]. The energy dissipation of flow in the stepped shape of gabion weir has a direct proportion with discharge, and an inverse proportion with both the ratio of length of the third step to the total length of the weir, the diameter of the gravel sample, and the porosity in general form, respectively [3]. Laboratory tests were done to investigate the flow over and through gabion weir, several models of gravel gabion weirs for various lengths, heights, and three different diameters of gravel sample. The results showed that reducing the mean size of the gravel in the gabion weir, caused the upstream water depth to increase. [4]. The hydraulic comparison of two different types of weirs: reinforced concrete and gabion was studied. Results showed that upstream sedimentation and downstream scouring were higher for concrete weirs as compared to gabion weirs but a low discharge coefficient was observed for the concrete weir, as compared to the gabion [5]. Both solid and gabion weirs with three various upstream/downstream slopes (90°, 45° and 26.5°) and different filling material were investigated.

Totally, twenty-four physical models were tested. The results showed that decreasing the upstream slopes, from 90º to 26.5º, resulted in a decrease in discharge coefficients [6]. The dissipated amount of energy for gravel gabion weir by choosing the difference in energy between upstream and downstream sides of the weir was studied [7]. There was a broad range of upstream water depth, height, weir length, discharge, and aggregate sizes for gabion filling. The results of a gabion weirs were compared with solid weirs of the same size, and it became apparent that the flow characteristics of the two types of weirs differed. [8]. Sixteen physical models were experimentally studied, four various lengths and four degrees of gravel coarseness. The results showed that as gravel coarseness increased from 1.13 to 2.72 cm, upstream flow depth decreased by 7% [9]. Four different heights and four various medium aggregate materials of rectangular gabion weir were studied. Results indicated power relationships for flow depth upstream related to discharge, gabion weir height, and medium aggregate material for each of the three flow regimes, though, transition and over flow were present [10]. Two horizontal lab flumes, two different gabion weir models, various weir heights, weir lengths, downstream and upstream water depths, and gabion infill gravel material sizes were investigated. The results showed that in the same discharge, the head over the gabion weir was lower than that over the solid weir, and the head dropped as the particle size of the gabion material increased [11]. The studied gabion stepped spillway models utilized an aggregate size that passed through a 12.75mm sieve and remained on a 4.75mm sieve [12]. The stepped gabion weir with a different shape and size of rock material filled was investigated. It is obvious that hydrological processes are significantly influenced by the shape of the rock [14]. An investigation in lab conducted transition flow on the gabion stepped structure and skimming flow on the smooth impervious stepped structure. For the smallest discharges on the gabion stepped chute, there was no overflow and the water permeated the gabions [15].

The literature shows that little research studied trapezoidal gabion weir. The main goal of the present research is to study the effect of upstream and downstream slops of trapezoidal weir and aggregate size (porosity) of gabion weir for free flow condition.

Theoretical Background

When porose weir is constructed in open channel, the flow can be divided into three regimes depending on the flowing discharge. If the discharge is adequate, water will flow over the top surface of the permeable weir. This type of flow is called overflow. This regime is the same as to the flow over impermeable broad-crested weir but with added flow across its body. However, when the discharge is not adequate, it will flow only through the front face of porous body structure. This type is known as through flow regime, but if the flow passes from both the front side and top surface, it is identified as transition flow regime. Figure (1) shows three regimes of flow for the case of the trapezoidal gabion weir.

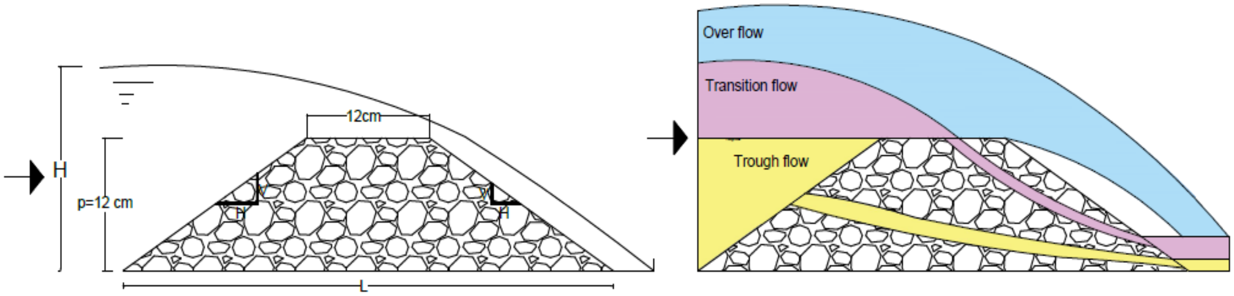


Figure (1) Regimes of flow at trapezoidal Gabion weir

The variables affected to flow discharge are used in the dimensional analysis, the upstream head of water from bottom of flume (H), weir height (p), bottom length of the weir (L) and the width of the flume (B).

Accordingly, the functional relationship for the regime can be expressed as:

$$H = f_1\,(H, Q, dm, L, B, p, g, \rho, \mu, \sigma) \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where **Q** is the discharge (L^3/T), **dm** is gravel size (L), **L** is the bottom length of the weir (L), B is the width of the flume (L), **p** is height of weir (L), **g** is the gravitational acceleration (L/T^2), **ρ** is the fluid's mass density (M/L^3), **μ** is the dynamic viscosity of the fluid (M/TL) and **σ** is the surface tension (M/T^2) .

The general relationship among all variables is:

$$f_2\,(H, Q, dm, L, B, p, g, \rho, \mu, \sigma) = \text{constant} \ldots\ldots\ldots\ldots \quad (2)$$

Using the Buckingham’s Pi – theorem,

$$= f_3\left(\frac{H^{1.5}Bg}{Q^2}, \frac{H}{L}, \frac{dm}{L}, \frac{B}{L}, \frac{\mu h}{\rho Q}, \frac{\sigma H^3}{\rho Q^2}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

In which

$\frac{\mu h}{\rho Q} = Re = Reynolds\ number, and$

$\frac{\sigma H^3}{\rho Q^2}$ = W_e=Weber number

In turbulent flow the value of Reynolds number and Weber number can be neglected due to neglect viscosity and surface tension. Throughout the whole experimental procedure, B and ρ remain constant., therefore can be dropped, taking inversing and square root of the $h^5\ g\ /Q^2$, Eq (3) can be written as, we get

$$\frac{Q}{\sqrt{g}\ BH^{1.5}} = f_4\left(\frac{H}{p},\frac{H}{L},\frac{dm}{H}\right)\text{.............................} \quad (4)$$

The value of is a coefficient of discharge is:

The coefficient of discharge is defined as actually discharged measured during an experiment to the discharged calculated under perfect circumstances called theoretical discharge (Q_{th}).

$$Cd = \frac{Q_{act}}{Q_{th}}\text{......................................} \quad (5)$$

$$Cd = \frac{Q}{\sqrt{g}\ BH^{1.5}} = f_5\left(\frac{H}{p},\frac{H}{L},\frac{dm}{H}\right)\text{............} \quad (6)$$

Experimental Work

All laboratory tests were conducted in a rectangular water flume at Duhok University's Engineering College's Hydraulic Laboratory, having 2.5 m long working section with a constant cross section of 7.6 cm wide and 25 cm in depth with toughened plastic walls on both sides to provide clear visibility and visual observation of the flow characteristics along its full length. A flow meter with a 0.5–2.5 L/s range was used to measure the discharge of the flume.

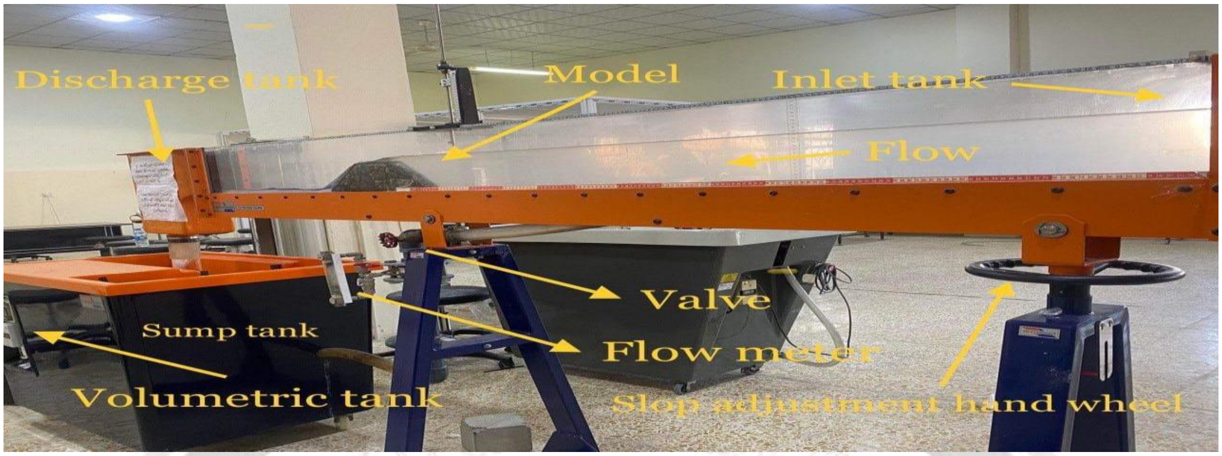


Figure (2) The experimental flume

Twelve models were constructed and tested during the experimental programme. The weir height and top length of the trapezoidal weir were kept constant (12 cm) for all the models. The dimensions of the trapezoidal weirs were determined by the flume size utilized in the laboratory work. The whole experimental models can be divided into three groups depending on the upstream and downstream slopes of trapezoidal weir (1:1,1:1.5, and 1:2). **For each trapezoidal weir, the flow coarsened the gravel, resulting in a distribution with four mean diameter sizes**: (1.13, 1.58, 2.19, and 2.72cm). Table (1) shows the details of the experimental program. Each model was set 1.5-meter distance from the front of the flume. The flow rate and the upstream flow height were recorded for each run, upstream flow depth was measured at a distance away from upstream for each model by a point gauge. A total of 153 experiments were conducted.

Table 1: Description of the tested models

Model No.	Weir height(P cm)	Top length(cm)	Gravel size (dm) cm	Porosity	Upstream slope (V:H)	Downstream slope (V:H)	Range of discharge (L/sec)
1,2,3, and 4	12	12	1.13, 1.58, 2.19, 2.72	33%,34%,36% and 38%	1:1	1:1	0.0437-1.78
5,6,7, and 8			1.13, 1.58, 2.19, 2.72	33%,34%,36% and 38%	1:1.5	1:1.5	0.062-1.19
9,10,11, and 12			1.13, 1.58, 2.19, 2.72	33%,34%,36% and 38%	1:2	1:2	0.087-1.33

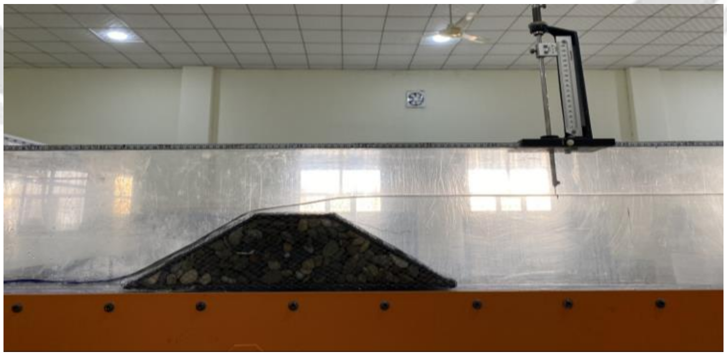


Figure (3) Trapezoidal Gabion weir during experiment

Results and Discussion

1. Variation of discharge (Q)with the head of water(H):

Within the limitation of the current study, the variation of discharge **(Q)** with upstream flow depth (H) was investigated for all models with various side slopes (S= 1:1, 1:1.5, and 1:2) and various porosity. Fig (4) shows that as discharge (Q) increases, the upstream flow depth (H) increases for each individual curve and for all experimented tests. The obtained relationships between the upstream flow depth and the actual discharge measured can be defined by logarithmic equations with a high determination coefficient (R^2). The figure also shows an increase in aggregate roughness from 1.13cm to 2.72cm, causing an increase in the amount of water penetrating through the trapezoidal gabion weir or decrease in the upstream flow depth(H). A greater medium diameter of aggregate allows more rates to flow through for the same head. This result has already been published by Jalil et al. (2019). The increase in aggregate roughness from 1.13cm to 2.72cm caused increase the amount of actual discharge measured from 17.5% to 35.8%.

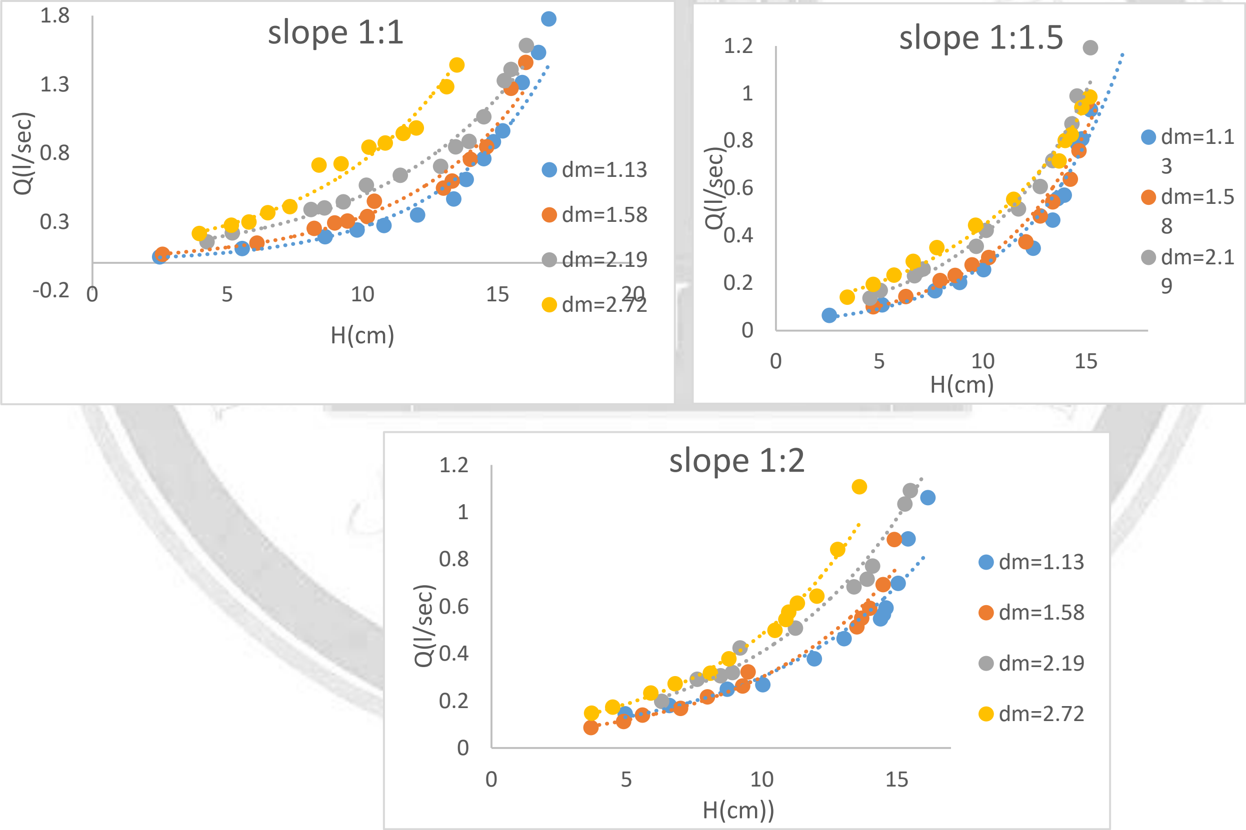


Figure (4) Discharge variation with upstream flow depth for different aggregate roughness and different side slopes

2. Variation of (Q) with ($\frac{H}{L}$):

The variation of discharge (Q_) with (H/L) was investigated for all models with various side slopes (S= 1:1, 1:1.5,1:2) and for each aggregate size. Fig. (5) illustrates the relationship. The obtained relationships between the discharge and upstream flow depth to the bottom length of trapezoidal gabion weir can be defined by exponential equations with a high determination coefficient (R^2). The figure shows for the individual model, the increase (H/L) led to an increase in discharge. This result has already been published by Jalil et al. (2019). The percentage of actual discharge is increase from 16% to 50% due to change side slopes from 1:1 to 1:2.

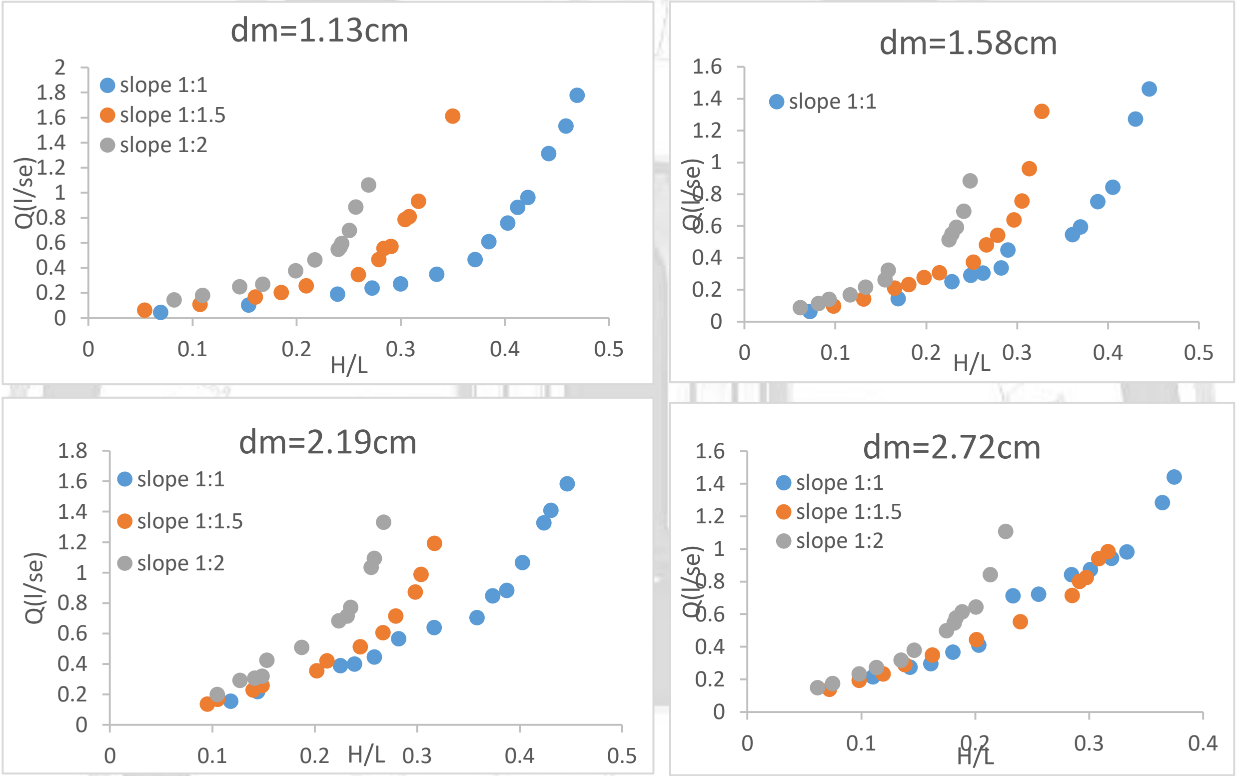


Figure (5) Discharge variation with H/L for a different side slope and different aggregate size

3. Predication of upstream flow depth:

A forecasting equation to find upstream flow depth for trapezoidal gabion weirs from the dependent variables Q, L, and dm was investigated. The SPSS software and nonlinear regression were used as

$$H = 6.995 * Q^{0.439} * L^{0.233} * dm^{-0.256} \qquad \text{--(7)}$$

Where, H(cm),Q(l/s),L(cm) and dm(cm).

Has a coefficient of determination R=0.943. A comparison of the values of (H) calculated by

Equation (7) and those seen through experimentation showed pretty good agreement, as evident in Fig. (6)

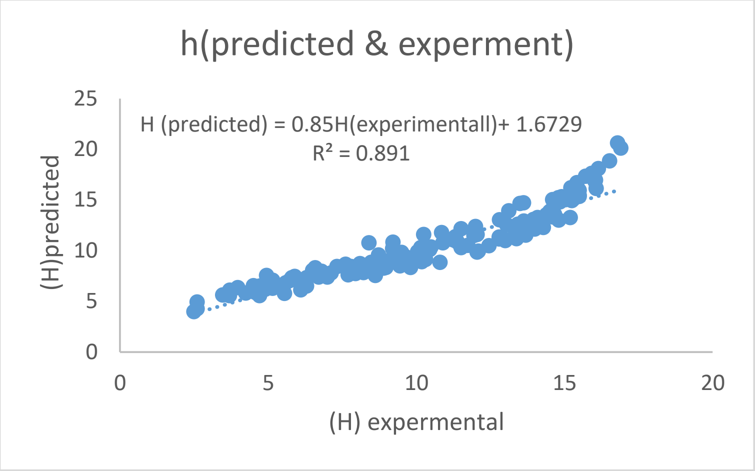
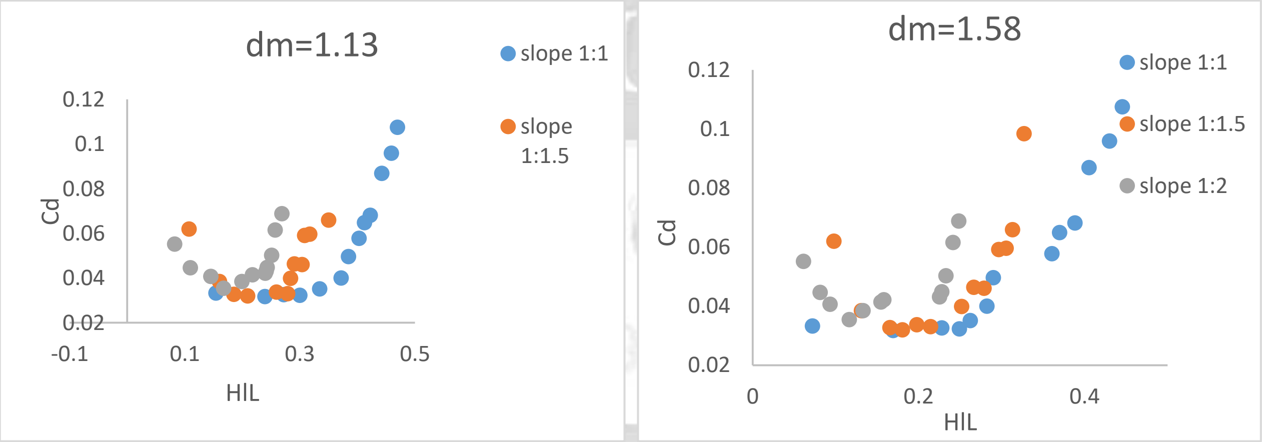


Figure (6) Observed and predicted upstream flow depth

4.Variation of (Cd) with $(\frac{H}{L})$:

Fig. (7) shows the relation between the coefficient of discharge Cd = (Q/(√g BH^ 1.5) to H/L. The figures show that with the increase in H/L cause the coefficient of discharge increased and the value of Cd increased with the increase in the side slopes of trapezoidal gabion weir from (1:1 to 1:2).



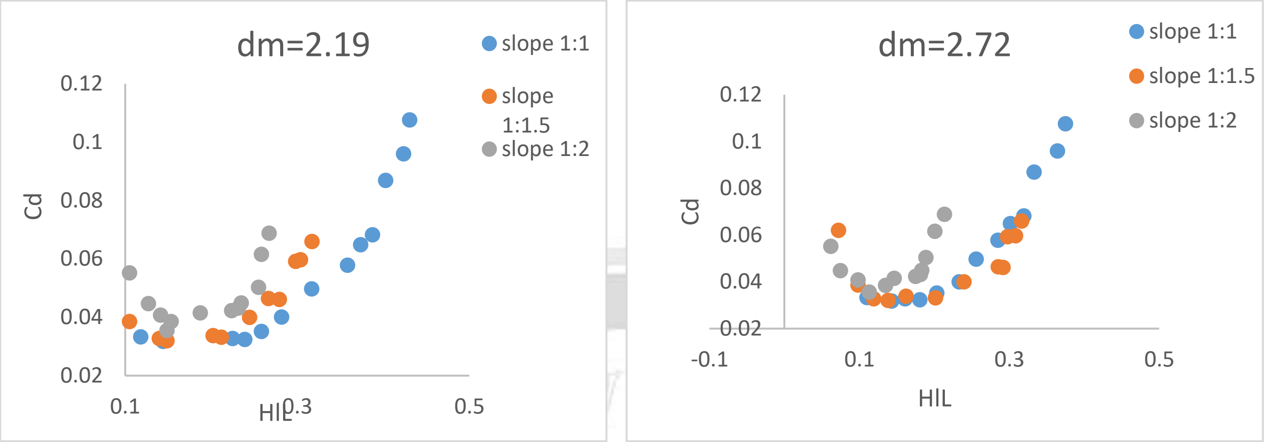
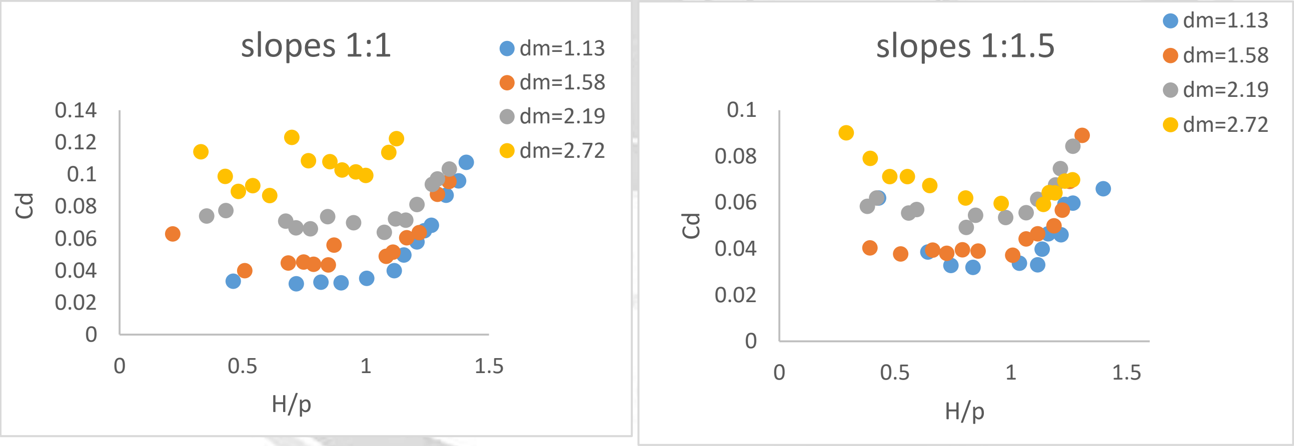


Figure (7) Variation of the coefficient of discharge with (H/L) for different aggregate roughness

5.Variation of (Cd) with ($\frac{H}{p}$):

Fig. (8) shows the relation between the coefficient of discharge Cd = (Q/(√g BH$^{1.5}$) to H/p. Cd increased as H/p increased and Cd increase as increase aggregate coarseness from 1.13cm to 2.72cm. Similarly, the discharge coefficient increased with the increase in porosity. This result has already been published by Salmasi et al. (2021).



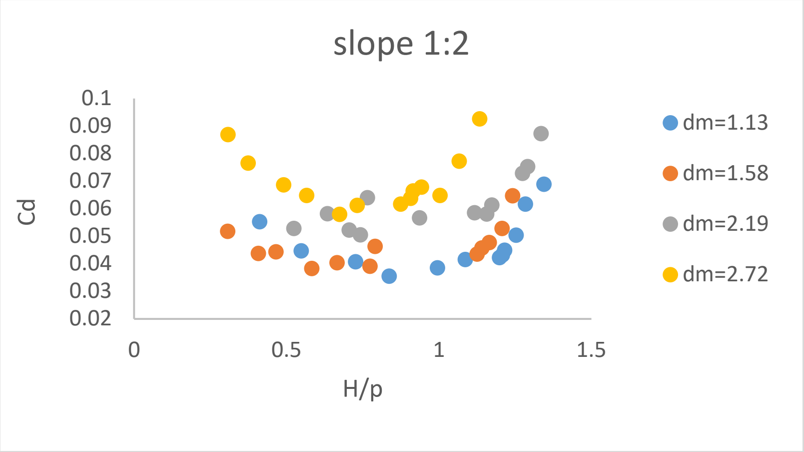
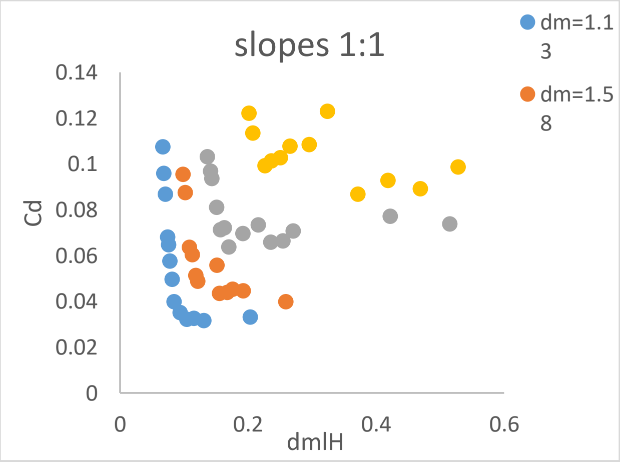
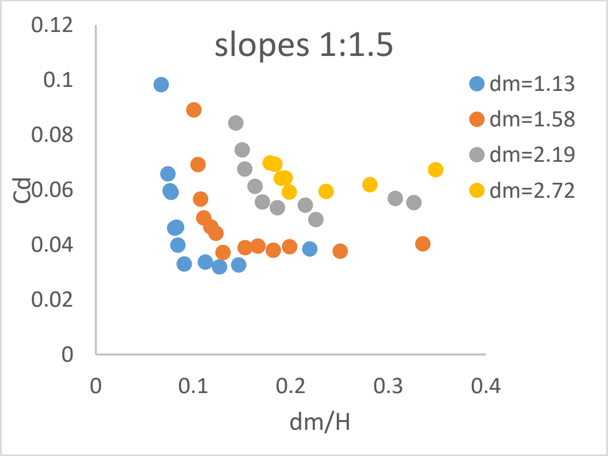


Figure (8) Variation of the coefficient of discharge with (H/p) and different aggregate roughness and different side slopes

6.Variation of (Cd) with ($\frac{dm}{H}$):

The values of coarseness-depth ratios (dm/H) were plotted against the coefficient of discharge Cd. It can be noted that the value of Cd increased with the increase in aggregate coarseness from 1.13cm to 2.72cm. But for a particular value of (dm/H), Cd decreased as (dm/H) increased. This result was agreed by Jalil et al. Fig. (9) illustrates the relationship.





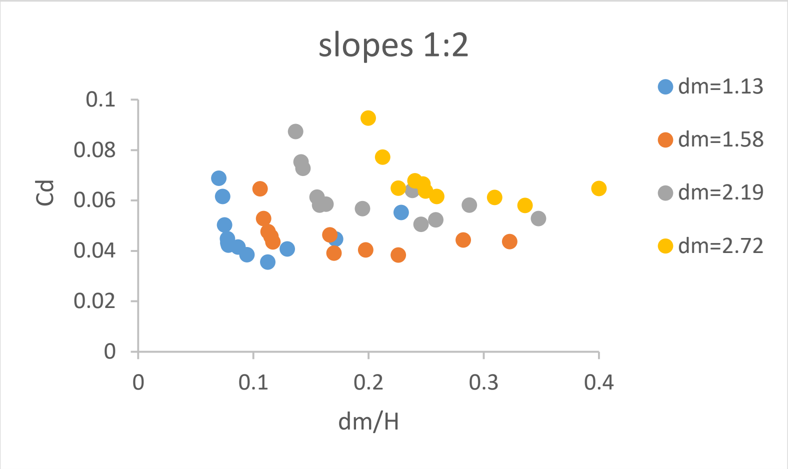


Figure (9) Variation of the coefficient of discharge with (dm/H) and different side slopes

6.Variation of (Cd) resulting from the combined influence of L/H, dm/H, and H/p:

The values of Cd for trapezoidal gabion weir were calculated based on equation (6). The experimental results of the twelve models were utilized as input data in the regression program SPSS in order to acquire an empirical linear expression of the form:

$$Cd = 0.133 * \frac{H}{L} + 0.179 * \frac{dm}{H} + 0.039 * \frac{H}{p} - 0.043 \qquad .... (8)$$

which has a coefficient of determination R = 0.8. The comparison between the values of Cd calculated by equation (8) and those seen through experimentation are shown in Fig.(10).

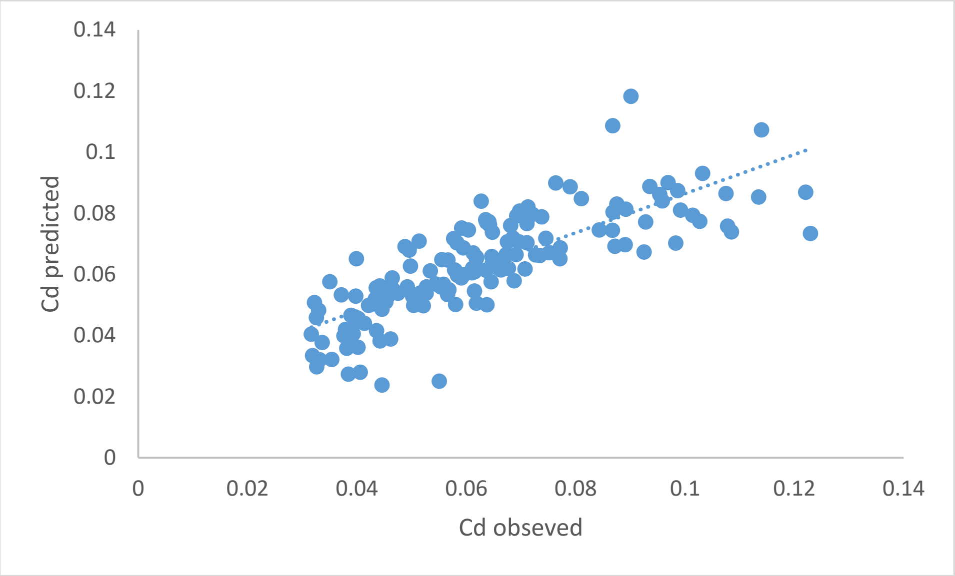


Figure (10) Observed and predicted coefficient of discharge by eq. (8)

Conclusions

In this study, twelve physical models of trapezoidal gabion weirs were tested and conducted to investigate some aspects of hydraulic performance of trapezoidal gabion weirs. Considering the boundaries of the current work, the results are discussed in the following conclusions:

1. The increase in aggregate roughness from 1.13cm to 2.72cm caused increase the amount of actual discharge from 17.5% to 35.8%.
2. The increase in discharge(Q) caused an increase in the (H/L) for all the models. The percentage of actual discharge is increase from 16% to 50% due to change side slopes from 1:1 to 1:2.
3. An empirical expression in the form of power functions is proposed to predict upstream depth flow H in terms of discharge Q, height of weir P, and gravel roughness dm, with correlation coefficients of 0.943.
4. In this study the main parameters that affected Cd were $\left(\frac{H}{p}, \frac{H}{L}, \frac{dm}{H}\right)$.
5. The discharge coefficient increased with increased porosity and increase the side slops from (1:1 to 1:2) also cause the coefficient of discharge increase.
6. For empirical expressions, linear regression was obtained to predict Cd in terms of $\left(\frac{H}{p}, \frac{H}{L}, \frac{dm}{H}\right)$, correlation coefficients 0.8.
7. The values predicted by the generated equations were found closely corresponding to the experimented values.

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اداء التدفق من خلال وفوق الهدارات الحصوية شبه المنحرفة

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الخلاصة

دُرست هدارات الحصوية ذات شكل شبة المنحرفة بمختلف الميول في مقدم الهدار و موخر الهدار مختبريا في قناة مائية مفتوحة. تم قياس عمق الماء في مقدم الهدار والتصريف من خلال التجارب العملية. وفُحص اثنا عشر نموذجا في قناة مائية مختبرية. تضمنت الإختبارات التجريبية ثلاثة أنظمة للتدفق (التدفق من خلال ، والتدفق الانتقالي، والتدفق فوق الهدار) في ظل ظروف السطح الحر للماء. تغيرت ميول الهدارات شبه المنحرفة ثلاث مرات (1: 1 ، 1: 1.5، 1: 2). لكل ميل من الهدار شبه المنحرف تغيرت حجم الحصى أربع درجات (1.13 ، 1.58 ، 2.19 ، 2.27 سم). أظهر تحليل النتائج التجريبية أنه مع زيادة خشونة المواد، ارتفاع نسبة التصريف العابر خلال الهدار بالنسبة 17.5%. الى 35.8%. . أظهرت جميع النماذج أن التصريف (Q) يرتبط بنسب ارتفاع الماء عند المنبع إلى طول الهدار (H/L) وتزداد نسبة التصريف من 16٪ إلى 50٪ عند تغيير المنحدرات الجانبية من 1: 1 إلى 1: 2 .معامل التصريف يرتبط بـ (H/L، H/p، dm/H). يزداد معامل التصريف مع زيادة خشونة الحصى (المسامية) اي ان العلاقة بينهما علاقة طردية كما ان زيادة المنحدرات الجانبية من (1: 1 إلى 1: 2) تسبب أيضا زيادة معامل التصريف. . قُدم نموذجان رياضييان ، أحدهما لعمق تدفق الماء في مقدم الجريان ، والثاني لمعامل التصريف المتوقع لأنظمة التدفق الثلاثة. وأظهرت النتائج ان القيم المختبرية والقيم المحسوبة بالمعادلات المقترحة ذات درجة عالية من الارتباط.

الكلمات الدالة: سد ذو مسامية، الحصوية، معامل التصريف، السد شبه المنحرف، التدفق الحر.