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FLOW THROUGH AND OVER GRAVEL GABION WEIRS

الجريان من خلال وفوق هدارات السلال الحصوية

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Abstract

Gravel and Rockfill gabions are commonly used in hydraulic structures such as self-spillway dams, cofferdams, and head regulators for water distribution or other purposes. A laboratory experiments were conducted to study the influence of gravel mean size, which consists of gabion, length and height of gabion on its upstream water depth. The present study included two cases of flow regimes, through and transient flow. In this study, different gravel gabion weir models were tested in horizontal laboratory flumes of *10m* length, *0.3m* width, and *0.5m* depth, for various weir lengths and heights using a wide range of discharges. Monosized gravel was used as filling material for the weir models. The gravel samples used in this study were three monosized gravel samples with diameters (-14+10), (-20+14), and (-25+20) *mm*. The results showed that for throughflow regime; upstream water depth of the gabion weir increases by decreasing the gravel mean size for the same weir length. In addition, for same gravel size, upstream water depth of the gabion increases by increasing the weir length. The results indicated that the relation between upstream water depth and unit discharge passing through gabion weir is linear for through and transient flow regimes. A positive and significant correlation was found between upstream water depth and unit discharge with an average $R^2$of *0.99* and *0.97* for through and transient flow regimes respectively. Based on dimensional analysis concept, multiple regression analysis equations were developed for computing the upstream water depth of the gabion weir at throughflow and transition flow regimes.

Keywords: Gabion; Throughflow; Transient flow; Hydraulic structures; Weir.

الخلاصة

تستخدم هدارات السلال الحصوية والركامية بشكل شائع في المنشات الهيدروليكية كسدود ذاتية المطفح او كسدود تحويل او كنواظم رأسية لتحويل وتوزيع مياه الري او لاغراض اخرى.اجريت التجارب المختبرية لدراسة تاثير معدل قطر الحصى المكون للسلة الحصوية وطول وارتفاع السلة على عمق الماء في مقدم السلة تحت تأثير جريان الماء .يتضمن البحث حالتين لانظمة الجريان خلال الهدارات الحصوية هما الجريان الخلالي والجريان الانتقالي.تم في هذا البحث فحص نماذج سلال حصوية باستخدام مواد حصوية مالئة احادية التدرج باحجام مختلفة.لانجاز البحث تم استخدام قناة مختبرية افقية بطول 10m وعرض 0.3m وعمق 0.5m ،حيث كونت النماذج المفحوصة باطوال وارتفاعات مختلفة وفقا لحالة الجريان مع استخدام مدى واسع للتصاريف المارة من خلالها وفوقها.تم انجاز التجارب المختبرية باختيار ثلاث نماذج من الحصى النهري الاحادي التدرج هي (-14+10)mm و (-20+14)mm و (-25+20)mm . بينت نتائج الجريان الخلالي بانه لنفس وحدة التصريف وطول الهدار الحصوي فان ارتفاع الماء في مقدم الهدار يزداد كلما قل القطر الممثل للحصى المستخدم .كما اظهرت نتائج الجريان الخلالي بانه لنفس التصريف وقطر الحصى فان ارتفاع الماء مقدم الهدار يزداد بزيادة طول الهدار. بينت نتائج البحث بانه لحالتي الجريان فان العلاقة بين عمق الماء في مقدم الهدار الحصوي ووحدة التصريف المار خلاله وفوقه لجميع احجام الحصى والابعاد المستخدمة هي علاقة خطية بقيم معامل ارتباط R^2 هي 0.99 و0.97 لنظامي الجريان الخلالي والانتقالي على التوالي.وباستخدام اسلوب الانحدار الخطي والمتعدد واعتمادا على نظرية التحليل البعدي تم التوصل الى معادلات خاصة لحساب عمق الماء في مقدم الهدار الحصوي للجريانين الخلالي والانتقالي اعتمادا على التصريف المار عبر السلة الحصوية والقطر الممثل للمواد الحصوية والابعاد الهندسية للهدار.

1. INTRODUCTION

Flow through gravel weirs is of fundamental importance to a wide range of disciplines including water resources engineering, hydrology, and chemical engineering. Generally, impermeable weirs that constructed of concrete, metal, rubber, etc. were used in various engineering applications, but nowadays alternative weirs made of porous media such as gravel gabion weir **GGW** are preferred since the latter can better meet natural and ecological requirements. The **GGW** consist of gravel aggregates enclosed with a wire mesh grid. Economically, the **GGW** is less expensive compared with other types of weirs in areas in which gravel is readily available. Depending on the nature of the site, gravel aggregates are manufactured by crushing solid rocks and are also commonly found among glacial and floodplain soil deposits. The main function of weir is to reserve water and to regulate river flow for various purposes. An impermeable weir usually prevents the longitudinal movement of aquatic life and transportation of physical and chemical substances in water. So this has a negative impact on the river environment. The **GGW** is permeable but it reserves amount of water and it allows the rest of water to pass through its body. This, however, allows streamwise migration of aquatic lives. In addition, physical and chemical substances such as suspended organic matter and sediments could pass downstream through the **GGW** permeable body which minimizes negative impact of the gabion on stream environment. In compared to traditional types of impermeable weirs, the **GGW** is considered as an ecologically friendly structure.

In gravel or rockfill gabions, due to the large size of pores, the flow is inherently turbulent and therefore not amenable to a classic seepage analysis on the basic of Darcy's low, so a non-Darcy flow relationship must be used [1]. Few experiments conducted to study the hydraulic characteristics of flow through and over gravel and rockfill weirs have been reported because of the large apparatus required and of the physical difficulty handling the material. Those studies that are available generally indicate that the flow through gravel materials is not laminar and, therefore, does not obey Darcy's law and the relationship between flow velocity **v** and the hydraulic gradient, *(i)*, was of the form $(v = mi^k)$, with m and k are constants for particular gravel [2 and 3]. Kells, [4] studied flow through and over rockfill models. He showed that the ratio of through to overtopping flow as a discharge was in the range from to 0.25 to 0.5 for the experiments in his model. Michioku et al., [5], examined the hydrodynamics of a rubble-mound weir theoretically and experimentally. By performing a one-dimensional analysis on a steady non-uniform flow through the weir, they found that the discharge may be described as a function of related parameters such as flow depths on the upstream and downstream sides of the weir, porosity, and grain diameter of rubble mound, weir length. They found that it is possible to apply the rubble mound weir for practical use as a discharge control system. Michioku et al., [6], investigated the flow field around rubble mound weirs and groins experimentally. They found that mass and momentum exchange between the main flow and the rubbles porous media was predominant around the upstream and downstream corners of the weir and the groin, where the streamline was rapidly contracted. Chinnarasri et al., [7] found that the energy dissipation rate in a gabion-stepped weir depends on filling material porosity and weir slope. Mohamed, [8] studied the flow over gabion weirs. He indicated that the nature of flow over the gabion weir is different than that of the solid weir where the flow is divided into two parts, one over the weir and the other through the weir. He also showed that for the same discharge, the head over the gabion weir is less than that over the solid weir and the head decreases by increasing gabion material particle size. Salmasi et al., [9] examined the behavior of gabion-stepped weirs for energy dissipation. They found that the decision tree technique can be used as a reasonable method for classification of different parameters involved in energy dissipation through a gabion-stepped weir.

This paper aims to formulate upstream water depth for gabion weirs as a function of flow regime, gravel mean size, discharge, length of gabion, and geometric dimension of the gabion, and compares the results with those in previous literatures.

2. TYPES OF FLOW REGIMES FOR ROCKFILL WEIR

Depending on a hydraulic conductivity of rockfill materials and gabion's geometry for porous gabion weirs, five possible flow regimes can be observed [10]. As shown in Fig. 1, they are as below:

1. Non-overflow (throughflow): occur when the water flows only through the porous weir.
2. Non-overflow (throughflow) limit: is the state of flow that the free surface disappears from the upper edge of the weir crest.
3. Transient flow: is the state that the flow gets into the filling material over the weir.
4. Overflow flow limit: is the flow profile that the free surface reaches just the downstream edge of the weir crest.
5. Overflow flow: occur when the stream is running over the top of the weir.

In measurements and calculations, only throughflow and transition flow regimes are taken into consideration in this study.

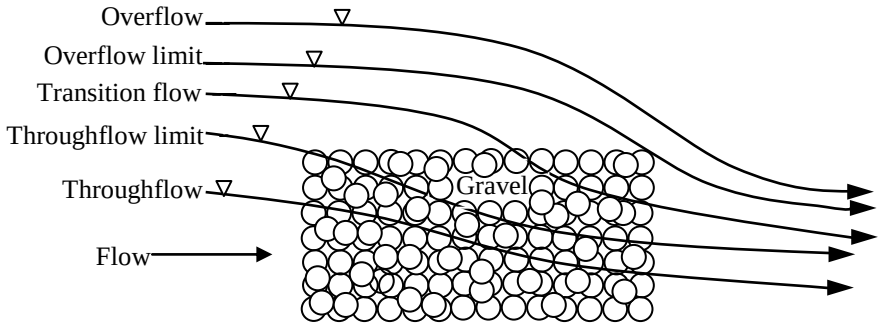

Figure 1. Flow regimes for porous gabion weir.

3. LABORATORY EXPERIMENTS

All laboratory experiments were conducted in a glass-sided tilting flume with a fabricated stainless steel bed *10 m* long, *0.3 m* wide and 0.5 *m* deep as shown in Fig. 2.

Figure 2. View of flume used in the study.

Experiments were carried out at the fluid mechanics laboratory of the civil engineering department in al- Mustansiriya University (Iraq). Water was circulated through the flume by an electrically driven centrifugal pump providing a maximum flow of *28 lps*. Water flow rates were measured by means of a triangular weir. The longitudinal flume slope fixed with 0^o angle of inclination. In the present paper three monosized rounded gravel samples were chosen with nominal diameters (-14+10) *mm*, (-20+14) *mm*, and (-25+20) *mm*.

Porosity *n* of a porous media sample was defined as the volume of voids within a porous media divided by the bulk volume of the sample. It was evaluated for each sample by randomly dumping the test gravel into a tank, weighing the tank and gravel, filling the tank with water; weighing the tank, gravel and water; arithmetically determining the volume of water, which was equivalent to the volume of voids; *n* may be expressed as equation:

$$n = \frac{V_v}{V_b} \tag{1}$$

in which

V_v = voids volume in a sample, (L^3), and

V_b= bulk volume of the sample, (L^3).

For each gravel sample, the equivalent gravel diameter, particle density, porosity and shape factor were determined. To estimate the shape factor **SF** [11], three major axes were measured for the gravel particles using a vernier and the average axes lengths calculated for each sample. Shape factors were estimated using the relationship

$$SF = \frac{c}{\sqrt{ab}} \tag{2}$$

in which

a= length in longest direction, (*L*), and

b and c= lengths measured in mutually perpendicular medium and short directions , (*L*).

Figure 3 shows the three dimensions **a**, **b**, and **c**. Table 1 summarises the properties of the three samples randomly drawn from each of the three materials.

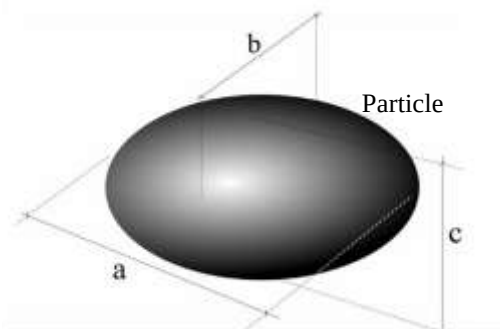

Figure 3. Gravel particle principal axes.

Table 1. Properties of the three gravel samples.

Monosized sample mm	Gravel mean size mm	Particle Density (g/cm^3)	Porosity	Shape Factor
(*-14+10*)	12	2.69	39.16%	0.53
(*-20+14*)	17	2.72	40.7%	0.48
(*-25+20*)	22.5	2.75	41.06%	0.57

In this paper, the gravel samples were tested in a rectangular section contained in a wire mesh gabion with vertical upstream and downstream faces as shown in Fig. 4 with two flow regimes throughflow and transition flow .

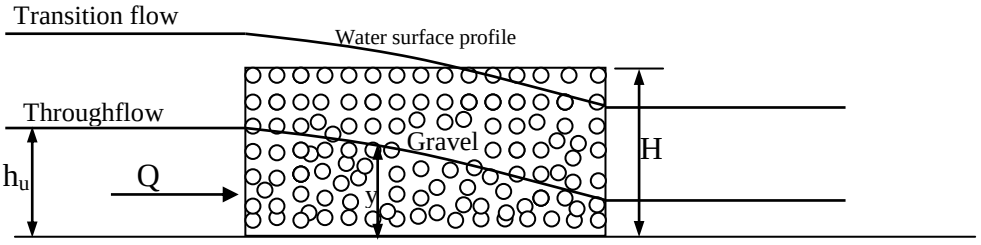

Figure 4. Definition sketch of models used in the experiments.

The experiments were conducted for various ranges of gabion height and two weir lengths *30 cm* and *60 cm*. The experimental conditions for the flume experiments are listed in Tables 1 and 2, respectively. The total number of experimental runs or data points was *63* runs for through and transient flow experiments.

Table 2. Experimental condition for through flow regime.

Parameter	Symbol	Value	Range		Units
			From	To	
Gravel mean size	d_m	Various	12	22.5	mm
Gabion length	L	30,60	-------	-------	cm
Gabion height	H	18	-------	-------	cm
Gabion width	W	30	-------	-------	cm
Unit discharge	q	Various	$1.59E^{-3}$	$7.35E^{-3}$	$m^3/s/m$

Table 3. Experimental condition for transition flow regime.

Parameter	Symbol	Value	Range		Units
			From	To	
Gravel mean size	d_m	17	-------	-------	mm
Gabion length	L	30,60	-------	-------	cm
Gabion height	H	Various	10	18.5	cm
Gabion width	W	30	-------	-------	cm
Unit discharge	q	Various	$4.2E^{-3}$	$13.3E^{-3}$	$m^3/s/m$

The laboratory work included the examination of the gravel samples for the two regimes, through and transient flow according to experimental conditions shown in Tables 2 and 3. This work was carried out according to the following steps:

1. Manufacturing a metal frames with a wire mesh with various dimensions of gabion height and length as shown in Tables 2 and 3.
2. Putting the first metal frame (*L=0.30 m*), *3 m* from the flume head as the gabion dimensions (height and width) shown in Table 2.
3. Constructing the gabion for throughflow regime experiments by randomly dumping the test gravel with a monosized diameter *12 mm* in the metal frame as shown in Fig. 5.
4. Establishing a flow rate by adjusting a control valve in the flume supply line.
5. Waiting *30 min* so that upstream water depth equilibrium is established.
6. Recording the discharge, flow depth at the gabion upstream face, and water depth at the gabion downstream face.
7. Changing the value of the discharge as in step 4.
8. Repeating steps 5 to 7 several times.
9. Repeating steps 3 to 8 for other test gravel sizes and lengths shown in Table 2 for throughflow regime experiments.
10. Repeating steps 2 to 9 for other gabion length (*L=0.60 m*) as shown in Table 2.
11. Repeating steps 2 to 8 using gravel of *17 mm* diameter only according to the gabion dimensions as in Table 3 for all gabion heights (10, 12, 16.5, 17, 18, 18.5 cm), producing transient flow experiments.

Figure 5. View of gabion weir used in the study.

4. DIMENSIONAL NANLYSIS

The upstream water depth for the **GGW** depends on many variables such as the properties of the filling material, discharge, and geometric of the weir. A physically pertinent relation between the upstream water depth and other variables may be found by dimensional analysis. The nondimensional relationship is also useful for checking the sensitivity of the different parameters which affect the phenomenon [11].The functional relationships of the water depth upstream the gabion weir h_u for through and transient flow may be expressed as below:

4.1 Throughflow regime

The relationship for this condition can be expressed as follows:

$$h_u = f(\rho, g, q, L, d_m) \quad (3)$$

in which
h_u=upstream water depth (L),
L=gabion length, (L),
d_m= mean gravel size used in gabion construction, (L),
ρ =water density, (ML^{-3}),
g=gravity of acceleration, (LT^{-2}), and
q=discharge per unit width of the flume (unit discharge), (L^2T^{-1}).

4.2 Transition flow regime

In general the relationship for this condition can be expressed as follows:

$$h_u = f(\rho, g, q, L, H, d_m) \quad (4)$$

For a particular gravel size the relationship for transition regime can be written as follow:

$$h_u = f(\rho, g, q, L, H) \quad (5)$$

Depending on the relationships (3) and (5), some transformations lead to the non-dimensional relations (6) and (7) for throughflow and transition flow respectively.

$$\frac{q}{g^{0.5} h_u^{1.5}} = \Phi\left(\frac{L}{h_u}, \frac{d_m}{h_u}\right) \quad (6)$$

$$\frac{q}{g^{0.5} h_u^{1.5}} = \Phi\left(\frac{L}{h_u}, \frac{H}{h_u}\right) \quad (7)$$

In the following section the dimensionless groups in the relations (6 and 7) will be correlated to give an explicit equation for computing the water depth upstream the **GGW** at the throughflow and transition flow regimes.

5. RESULTS AND DISCUSSIONS

This paragraph describes the presentation and discussion of the results for throughflow regime and transition flow regime as follows:

5.1 Throughflow regime

Figure 6 shows the relation between upstream water depth and unit discharge passing through the gravel gabion weir with different filling material sizes and two gabion lengths *30 cm* and *60 cm*. It is obvious that the relation between $\boldsymbol{h_u}$ and $\boldsymbol{q}$ is linear for all gravel sizes and for same discharge and gabion length, $\boldsymbol{h_u}$ value increases by decreasing the mean gravel size of the gabion weir. For $q=0.005\ m^3/sec/m$ and $L=30\ cm$, the $\boldsymbol{h_u}$ values at $\boldsymbol{d_m}$ of *12, 17,* and *22.5 mm* are 0.143 *m*, 0.125 *m*, and 0.115 *m* respectively. This result agreed with the results of previous studies [8, 12, and 13]. It can be shown that for same discharge and mean gravel size, $\boldsymbol{h_u}$ value increases by increasing the length of the gabion. For $q=0.004\ m^3/sec/m$ and $d_m=17\ mm$, the $\boldsymbol{h_u}$ values at $\boldsymbol{L}$ of *30*, and *60 cm* are 0.108 *m*, and 0.141 *m* respectively.

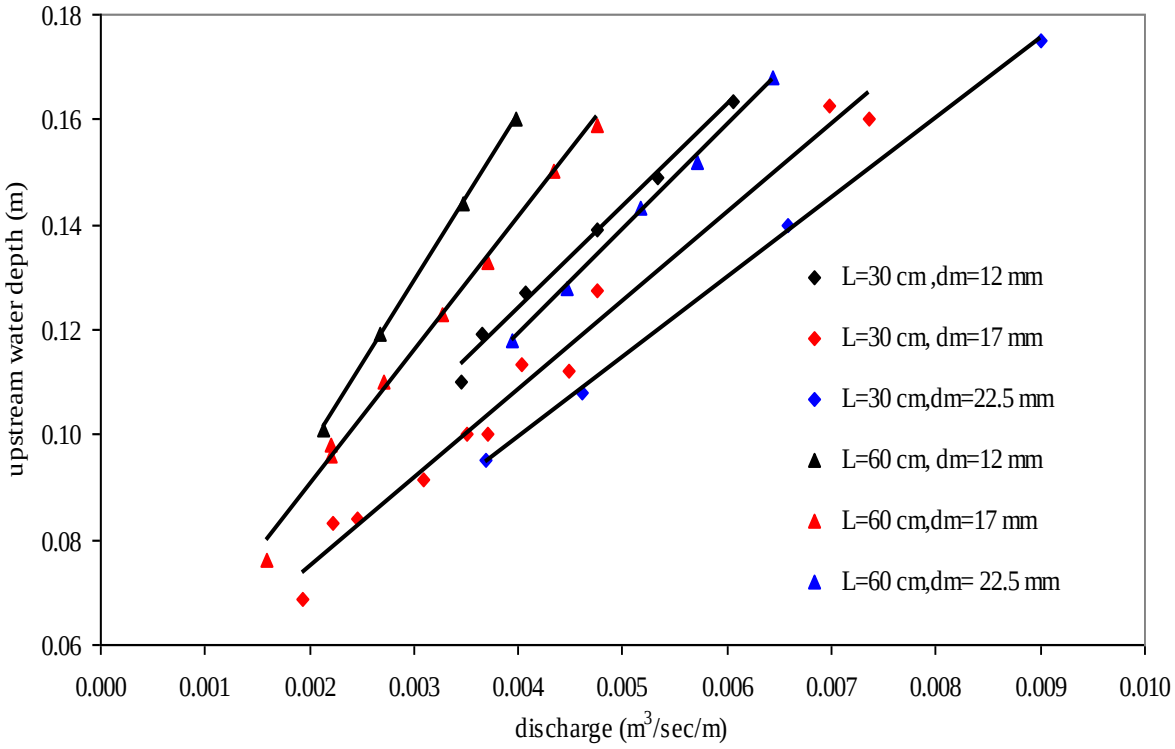

Figure 6. Measured values of upstream water depth for through flow regime.

Regression analysis with a linear function was used to obtain a formula to estimate $\boldsymbol{h_u}$ values. Table 4 shows the formulas for estimating $\boldsymbol{h_u}$ under throughflow regime with different conditions, in which $\boldsymbol{h_u}$ in *m* and $\boldsymbol{q}$ in $m^3/sec/m$.

Table 4. Formulas for estimating h_u of throughflow regime.

d_m (mm)	L (m)	h_u formula	R^2
12	0.3	h_u=19.411q+0.0462	0.99
17	0.3	h_u=16.865q+0.041	0.98
22.5	0.3	h_u=15.169q+0.0389	0.999
12	0.6	h_u=31.833q+0.0334	0.999
17	0.6	h_u=25.397q+0.0395	0.999
22.5	0.6	h_u=19.965q+0.0391	0.999

Table 4 shows that for the same length of the weir gabion, effect of $\boldsymbol{q}$ on $\boldsymbol{h_u}$ increases by decreasing gravel mean size and for the same gravel mean size, the effect of *q* on h_u increases by increasing the length of the **GGW**. The slope of the linear relationships for throughflow regime between $\boldsymbol{h_u}$ and $\boldsymbol{q}$ of different states for gabion length of *0.3 m* and gravel mean size *12 mm*, *17 mm*, and *22.5 mm* are *19.41*, *16.86*, and *15.6* respectively.

In addition the slope of the linear relationships for throughflow regime between h_u and q for different states for gabion that consist of gravel of *12 mm* average diameter with a length *0.3 m* and *0.6 m* are *19.41* and *31.833* respectively.

A multi-linear regression analysis is used to correlate the different dimensionless parameters shown in relation (6) and develops an empirical equation for computing the upstream water depth at the throughflow regime. The developed equation was found with the correlation coefficient $R^2 = 0.94$ can be expressed as follows:

$$h_u = 1.607 \frac{q^{0.66} L^{0.349}}{d_m^{0.34}} \qquad (8)$$

in which h_u in *m*, L and d_m in *m*, and q in $m^3/sec/m$.

Figure 7 shows values of the computed h_u in dimensionless form from the regression analysis Eq. (8) versus the measured h_u. As shown from this figure, there is good agreement between the computed h_u and the measured one.

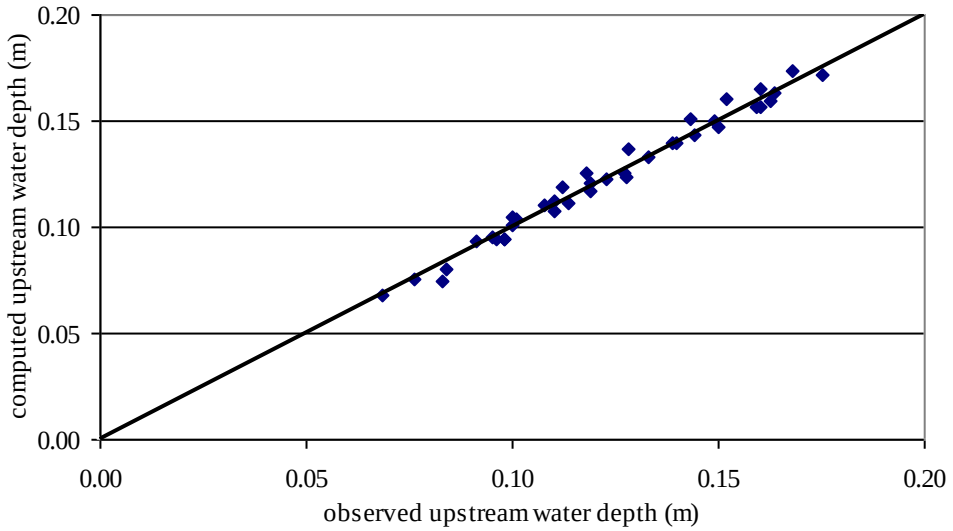

Figure 7. Computed value of upstream water level using Eq. (8) versus observed value at throughflow regime.

5.2 Transition flow regime

Figure 8 shows the measured values of h_u for transition flow regime versus the measured discharge at d_m of *17 mm* with different lengths and heights of **GGW**. It is obvious that for same gabion length, the upstream water depth for each discharge increases by increasing gabion weir height .For $q=0.008\ m^3/sec/m$ and $L=30\ cm$, the h_u values at heights of *0.1*, *0.165*, *0.18*, and *0.185 m* are 0.125 *m*, 0.175 *m*, 0.188*m*, and 0.197 *m* respectively.

Regression analysis with a linear function was used to obtain a formula to estimate h_u values. Table 5 shows the formulas for estimating hu with different conditions, in which h_u in *m* and q in $m^3/sec/m$.

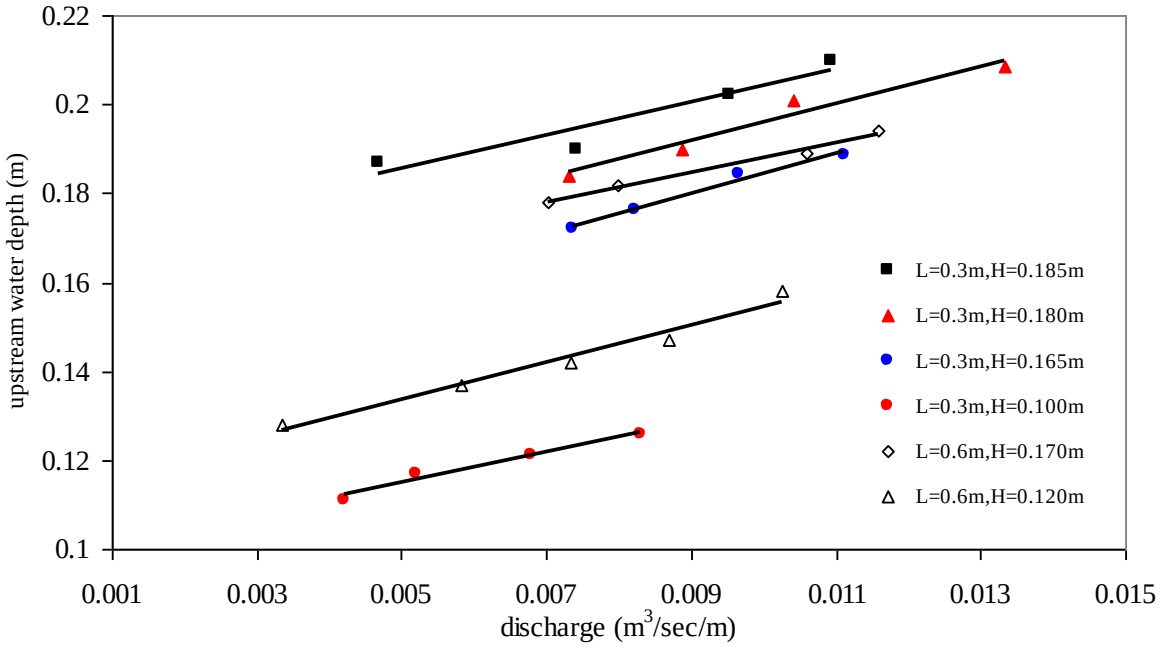

Figure 8. Measured values of upstream water depth at transition flow regime.

Table 5. Formulas for estimating h_u of transition flow regime.

H (m)	L=0.3 (m)	L=0.6 (m)	R^2
0.185	h_u=3.7261q+0.167	----------	0.90
0.180	h_u=4.1755q+0.1542	----------	0.96
0.165	h_u=4.5016q+0.1394	----------	0.98
0.100	h_u=3.4745q+0.0975	----------	0.97
0.170	----------	h_u=3.3011q+0.1551	0.99
0.120	----------	h_u=4.1453q+0.113	0.97

Tables 4 and 5 illustrate that the slope of $\boldsymbol{h_u}$-$\boldsymbol{q}$ relationship for throughflow regime is high great compared with that of transition flow regime.

A linear regression analysis is used to correlate the different dimensionless parameters shown in Eq. (7) and develops an empirical equation for computing the upstream water depth at the transient flow condition. The developed equation can be expressed as follows:

$$h_u = 1.624 q^{0.196} H^{0.704} L^{0.002} \quad (9)$$

in which h_u in *m*, H and L in *m*, and q in $m^3/sec/m$. The correlation coefficient R^2 was found to be 0.79.

Figure 9 shows values of the computed h_u in dimensionless form from the regression analysis Eq. (9) versus the measured values of h_u. As shown from this figure, there is good agreement between the computed h_u and the measured one.

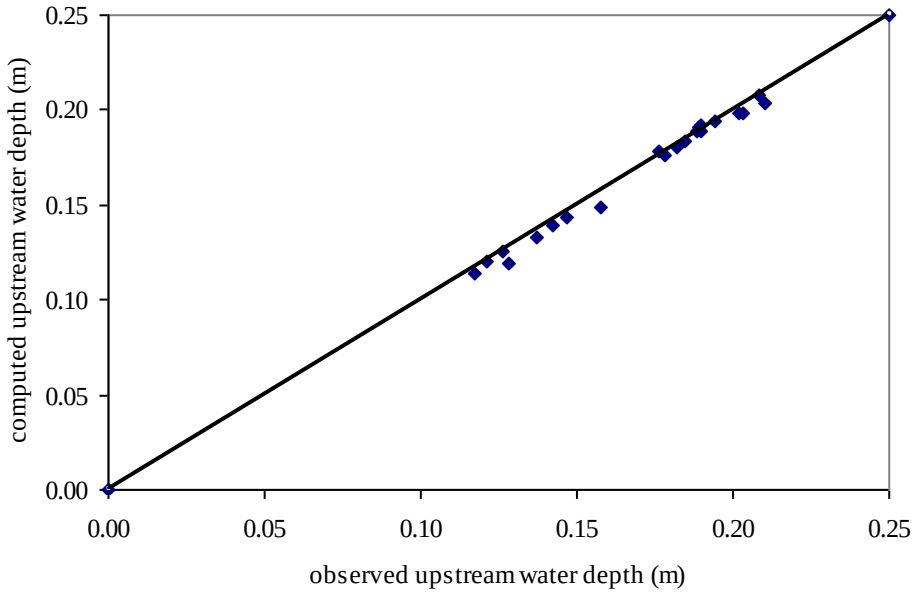

Figure 9. Computed value of upstream water level using Eq. (9) versus observed value at transition flow regime.

6. CONCLUSIONS

In this paper, a series of laboratory experiments were conducted to investigate the flow through and over the **GGW**. According to the results of the laboratory experiments, the following conclusions were found:

1. For throughflow regime, the relation between upstream water depth of the gabion and unit discharge through it is linear for all gravel sizes.
2. For same throughflow discharge and gabion length, upstream water depth value increases by decreasing the mean gravel size of the gabion weir.
3. For same through flow discharge and mean gravel size, upstream water depth value increases by increasing the length of the gabion.
4. Strong linear relationships were found between upstream water depth of the gabion and unit discharge through it for the three gravel sizes (*12mm, 17mm, 22.5mm*) with average R^2 equal to a *0.99*.
5. In transition flow regime, for same gabion length, the upstream water depth for each discharge increases by increasing gabion weir height.
6. In transition flow regime, strong linear relationships were found between upstream water depth of the gabion and unit discharge for the two lengths 0.3 m and 0.6 m with average R^2 equal to a *0.96*.
7. The slope of $\boldsymbol{h_u}$-$\boldsymbol{q}$ relationship for throughflow regime is high great compared with that of transition flow regime.
8. Based on dimensional analysis concept, multiple regression analysis equations were developed for computing the upstream water depth of the gabion at throughflow and transition flow regimes.

Notation

m= constants for particular gravel;
n=porosity;
Q=discharge;
q= unit discharge;
V=flow velocity;
V_b= bulk volume of the gravel sample;
V_v=void volume in a gravel sample;
W=weir width; and
ρ= water density.

The following symbols are used in this paper:
a, b, and c=particle axes lengths;
d_m=gabion filling material mean size;
g= gravity of acceleration;
H=weir height;
h_u=upstream water depth;
i=hydraulic gradient;
k= constants for particular gravel;
L=weir length;

7. REFERENCES

1. Majid H., Parisa H. T. (2011). "Prediction of flow through rockfill dams using a neuro-fuzzy computing technique". The Journal of Mathematics and Computer Science, 2 (3), 515-528.
2. Hansen, D., Garga, V., and Townsend, R. (1995). "Selection and application of a one dimensional non-Darcy flow equation for two-dimensional flow-through rockfill embankments". Can. Geotech. J., 32(2), 223–232.
3. Mulqueen j. (2005). "The flow of water through gravels". Irish Journal of Agricultural and Food Research, 44:83-94.
4. Kells, J. A. (1994). "Reply on discussion of spatially varied flow over rockfill embankments". Can. J. Civ. Eng., 21, 163–166.
5. Michioku, K., Maeno, S., Furusawa, T., and Haneda, M. (2005). "Discharge through a permeable rubble mound weir". J. Hydraul. Eng., 131(1), 1–10.
6. Michioku, K., Takehara, K., and Etoh, T. (2007). "An experimental study on flow field in and around rubble mound river structures". J. Hydrosci. Hydr. Eng., 25(2), 37–45.
7. Chinnarasri, Ch., Donjadee, S., and Israngkura, U. (2008). " Hydraulic characteristics of gabion-stepped weirs". Journal of Hydraulic Engineering, ASCE, Vol. 134, pp. 1147-1152.
8. Mohamed, H. I. (2010). "Flow over Gabion Weirs". Journal of Irrigation and Drainage Engineering, ASCE / Aug. 573-577.
9. Salmasi, F,Sattari, and M,Pal,M. (2012). "Application of data mining on evaluation of energy dissipation over low gabion-stepped weir". Turkish Journal of Agriculture and Forestry-Tubitak, (36):95-106.
10. Maeno S., Michioku, K., Morinaga, S., and Ohnishi, T. (2002). "Hydraulic characteristics of a rubble mound weir and its failure process". 5th ICHE Conference, Theme D.
11. Mohamed, H. I. (2005). "Discharge measurement in trapezoidal lined canals utilizing horizontal and vertical transitions". Proc., 9th Int. Water Technology Conf., IWTC9, Sharm El-Sheikh, Egypt, Mansoura, Egypt.
12. AL-Hashimi, G. H. (1988). "Hydraulic characteristics of flow through gravel self-spillway Dams". M.Sc. Thesis. College of Engineering, Mosul University, Iraq.
13. Shiko, A. A. (1989). "Hydraulic characteristics of over flow gravel dykes". M.Sc. Thesis. College of Engineering, Mosul University, Iraq.