Dissipation energy of Flow by Stepped Type Gabion Weir

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Abstract. The energy of flow can be defined in general form as a measure of an object's capability to perform work, and it can be done in many different forms. The present study aims to investigate the dissipated energy of flow in the stepped shape of gabion weir with three steps. A set of 25 laboratory experiments and 175 operation tests were carried out by using a laboratory flume channel with different discharges. The tested gabion weir has five different lengths, and the filling material used is natural quarry gravel with five different median diameter. The experimental data have been analyzed to correlate the energy dissipation with the independent dimensionless terms of the other variables. The results of analysis showed that the energy dissipation has a direct proportion with discharge, and an inverse proportion with both the ratio of length of the third step to total length of the weir, the diameter of the gravel sample, and the porosity in general form, respectively. The concluded equation of energy dissipation gives good agreement for comparison between measured and predicted values of energy dissipation.

Keywords: dimensional analysis; energy dissipation; gabion weir; physical models; stepped weirs.

1. Introduction
Dissipation of energy of flow in natural or artificial waterways is considered as one of the important topics in water engineering, especially in hydraulic engineering. Energy dissipation process can be accomplished by various techniques such as (1) High velocity water Nappe expelled from a flip bucket, and impinging into downstream pool, (2) Forcing a hydraulic jump downstream by constructing a stilling basin with an artificial macro-roughness, (3) Construction of stepped spillway to dissipate energy through turbulence created over the spillway face [3, 8, 19], and [21]. Energy dissipaters can be classified according to the material which it's made from into solid and pervious nature structures. Weirs in many textures and conditions used for energy dissipation of flow with effective performance [11], calculation of flow parameter coefficients [16], [25], [27], and [28], etc. Weirs are overflow structures built across open channels to measure the rate of flow of water in general form. They have been used for many years and offer a simple, reliable method for water measurements if they are built correctly and maintained properly [2]. Weirs with porous body are called "Gabion" weirs. Gabion weirs are more frequently found in river training, soil stabilization, and water supply schemes. In addition to flexibility which allows them to deform while remaining structurally sound, other advantages which gabion offer are relatively low cost and simplicity of construction [1]. Rockfill weirs protected by gabions stand much higher failure unit discharge than
earth weirs protected by gabions [26]. The gabion baskets can be fashioned into almost any shape that can be formed with concrete. The durability of wire-enclosed rock is generally limited by the service life of the galvanized binding wire which, under normal conditions, is considered to be about 15 years [13]. This paper aims to investigate the dissipated energy of flow for the stepped shape of gabion weir.

2. Laboratory Work
The tests were conducted in the laboratory of Fluid Mechanics, College of Engineering, University of Babylon, Iraq. The tilting flume has dimensions of 10 m length with 0.3 m width and 0.5 m height. The physical models that used have total lengths of 0.72, 0.84, 0.96, 1.08, and 1.20 m, and named as Stepped Gabion Weir, SGWA, SGWB, SGWC, SGWD, and SGWE, respectively. Figure 1 shows the general shape of the used gabion weir. All physical models have constant cross-section, width of 0.3 m and maximum step height of 0.4 m at upstream side, and steps of different heights and lengths as listed in table 1. The gravel samples used as filling material for the physical models were five monosized gravel samples with median diameters 11.75 mm, 16.5 mm, 22 mm, 31.25 mm, and 43.75 mm, and numbered as Gravel Sample Number, GS.1, GS.2, GS.3, GS.4, and GS.5, respectively. The frame of stepped gabion weir, SGW, was made of thin steel plated bars, covered by a wire mesh, and fixed inside the flume by silicone glue. A photo of SGWA with GS.1 is provided in figure 2. A centrifugal pump having a rated capacity of 40 l/s was used to deliver flow to the flume. Two movable carriages with point gauges were mounted on a rail at the top of flume sides which have accuracy of 0.1 mm to measure the depths of water. The first was located at the upstream side of the weir and for measuring the upstream water depth at equal distances 0.0 m, 0.2 m, 0.4 m, 0.6 m, 0.8 m, and 1.0 m before the weir. The other was at the downstream side of the weir for measuring the downstream water depth after the weir toe. A total of 175 operation tests were carried out at varying values of discharge from 0.7 to 15.0 litres per second.

3. Dimensional Analysis
The relationships between different parameters can be represented either by standard equations [7], [12], [26], and [29], empirical formulas, direct relationships, or correlated by using the dimensional analysis [4], [5], [6], [9], [10], [13], [14], [16], [18], [19], [20], [21], [22], [23], [24], [25], [28], and [29].

In case of the three steps stepped gabion weir, the relationships between influential parameters can be expressed functionally as [19] :

\[ f \{q, y_u, y_1, y_2, L_3, L, d_m, \rho, g, n\} = 0 \]

(1)

Where, \( q \) is the discharge per unit width (L²/T), \( y_u \) is the depth of water at the upstream side of weir (L), \( y_1 \) and \( y_2 \) are the depths of water at the downstream side of weir before and after the hydraulic jump, respectively (L), \( L_3 \) is the length of the third step of weir (L), \( L \) is the total length of weir (L), \( d_m \) is the equivalent diameter of the used gravel sample (L), g is the gravitational acceleration (L/T²), \( \rho \) is the Mass density (M/L³), and \( n \) is the porosity of the used gravel samples. These parameters can be classified into three main groups viz., Boundary dimensions; Flow dimensions; and Fluid dimensions [18]. In this study, the Boundary dimensions were represented by both of \( L_3 \), L, \( d_m \), and \( n \). The flow dimensions were represented by both of \( q \), \( y_u \), \( y_1 \), and \( y_2 \). Finally, the fluid dimensions were represented by both of \( \rho \) and \( g \).
Table 1. Details of step dimensions for all steps of the used gabion weir.

| Stepped gabion weir | 1st step dimensions | 2nd step dimensions | 3rd step dimensions |
|---------------------|---------------------|---------------------|---------------------|
|                     | h1 cm               | L1 cm               | h2 cm               | L2 cm               | h3 cm               | L3 cm               |
| A                   | 15                  | 40                  | 15                  | 20                  | 10                  | 12                  |
| B                   | 15                  | 40                  | 15                  | 20                  | 10                  | 24                  |
| C                   | 15                  | 40                  | 15                  | 20                  | 10                  | 36                  |
| D                   | 15                  | 40                  | 15                  | 20                  | 10                  | 48                  |
| E                   | 15                  | 40                  | 15                  | 20                  | 10                  | 60                  |

Note 1: h1, h2, and h3 present the effective distance of step height.

Note 2: L1, L2, and L3 are divided according to maximum weir length tested in this study, which is equal to 1.2 m where:
- L1 has a percentage of 33.3% of the maximum weir length.
- L2 has a percentage of 16.7% of the maximum weir length.
- L3 has a percentage of 10% of the maximum weir length, for SGWA, and the percentage of L3 increases accumulatively by 10% of maximum weir length with every physical model tested according to their arrangement in the table above.
The specific energy, $E$, defined as the energy referred to the channel bed as datum [15]

$$E = y + \frac{q^2}{2gy^2} \quad (2)$$

The energy at the upstream side of weir may be calculated by:

$$E_u = Z_u + y_u + \frac{q^2}{2gy_u^2} \quad (3)$$

While, the energy at the downstream side of weir will be

$$E_1 = y_1 + \frac{q^2}{2gy_1^2} \quad (4)$$

The difference in energy between the upstream and downstream sides of weir, $\Delta E$, can be calculated by:

$$\Delta E = E_u - E_1 \quad (5)$$

From equations (3), (4), and (5), it can be noticed that $E_u$ depends on $Z_u$ and $y_u$, and $E_1$ depends on $y_1$. So, the equation (1) can be re-written in the form of:

$$f_1 \{q, \Delta E, L_3, L, d_m, \rho, g, n\} = 0 \quad (6)$$

4. Results and Discussion

Factors Affect the Energy Dissipation

By using of dimensional analysis (Buckingham Pi – Theorem) to make a correlation among the parameters of equation (6)

$$\frac{\Delta E}{L} = f_2 \left\{ \frac{q}{L^{1.5} \rho^{0.5}}, \frac{L_3}{L}, \frac{d_m}{L}, n \right\} \quad (7)$$

4.1. Effect of the discharge parameter on the energy dissipation
In order to represent the relationship between the discharge and the energy dissipation, a non-dimensional data set was drawn in figure 3 for different diameters of gabion material. It was found that the best form of equation of trend line which represents the relationship between the discharge and energy dissipation was the power form.

\[
\frac{\Delta E}{L} = c_1 \left( \frac{q}{L^{1.5} g^{0.5}} \right)^{k_1}
\] (8)

where \(c_1\) and \(k_1\) are constants. From figure 3 it is clear that the energy dissipation value is directly proportional with the discharge value due to the detention property which the body of the weir has, at the same time the energy dissipation value decreases by increasing the value of \(d_m\) due to increasing the void ratio of gravel particles. This result agrees with what was previously identified by [7] and disagree however with the results of [5], [6], [9], [12], and [16], were they concluded that the energy dissipation increases by decreasing the discharge in stepped spillways. Table 2 shows the values of constants \(c_1\) and \(k_1\).

![Figure 3. The non-dimensional relationship between energy dissipation and discharge in the gabion weir.](image)

**Table 2.** Values of constants \(c_1\) and \(k_1\) of equation (8).

| Diameter of gravel sample (mm) | \(c_1\) | \(k_1\) | \(R^2\) |
|-------------------------------|--------|--------|--------|
| 9.5-14.0                      | 4.318  | 0.499  | 0.934  |
| 14.0-19.0                     | 4.644  | 0.546  | 0.899  |
| 19.0-25.0                     | 5.465  | 0.579  | 0.995  |
| 25.0-37.5                     | 5.732  | 0.606  | 0.904  |
| 37.5-50.0                     | 3.844  | 0.607  | 0.900  |

4.2. Effect of the ratio \(L3/L\) on the energy dissipation

Figure 4. shows the represented relationship between the energy dissipation dimensionless parameter and the \(L3/L\) ratio. From this figure, it's clear, in general form, that the energy dissipation value is
inversely proportional with \( \frac{L_3}{L} \) value, and this proportion starts to be lower in affection with increasing the value of \( d_m \).

![Figure 4](image4.png)

**Figure 4.** The non-dimensional relationship between energy dissipation and the \( \frac{L_3}{L} \) ratio of the gabion weir.

4.3. **Effect of the ratio of \( d_m/L \) on the energy dissipation**

Figure 5 represents the relationship between the energy dissipation dimensionless parameter and the \( d_m/L \) ratio. This figure obtained clearly that energy dissipation value is inversely proportional to \( d_m/L \) value in general form, and this proportion starts to be lower in affection with increasing the value of \( L \), and there is undulation in arrangement of gabion weir physical models due to the difference in response to energy dissipation. An agreement of this result was identified clearly by [7] and kindly by [10] where they concluded precisely that for high discharge values, increasing the particle sizes provides a higher ratio of energy dissipation, while for low discharges, the energy dissipation of smaller particles are higher.

![Figure 5](image5.png)

**Figure 5.** The non-dimensional relationship between energy dissipation and the \( d_m/L \) ratio of the gabion weir.
4.4. Effect of porosity of gravel sample on the energy dissipation

Porosity values which were calculated for this study were 48.75%, 51.63%, 52.31%, 52.56%, and 53.55% respectively. Figure 6 represents the relationship between the energy dissipation dimensionless parameter and the porosity of gravel sample used. From this figure it can be concluded that energy dissipation values generally have an inverse proportion with the values of porosity, but this indication appear clearly in smaller and larger lengths of the gabion weir, and start to disappear for middle lengths. This result was identified also by [10] where they concluded that increasing the upstream water head as a result of increasing the discharge will reduce the effect of porosity of the weir.

By using of multi-linear regression for the data set to correlate the dependent parameters with other independent ones as previously followed by [4], [5], [7], [9], [10], [16], [19], [20], [22], [24], [25], and [28], 60% of data were used for regression process by using of Microsoft Excel computer Program, (data collected for test runs of the 1st, 3rd, and 5th total lengths of the gabion weir), and 40% of data were used for verification of the resulted formula, (data collected for test runs of 2nd and 4th lengths of the gabion weir). The relationship between predicted and measured values of energy dissipation can be expressed as

\[
\frac{\Delta E}{L} = 0.274375 + 20.963831 \frac{q}{L^{1.5} g^{0.5}} + 0.027264 \frac{L^3}{L} - 4.003808 \frac{d_m}{L} - 0.057083 \ n
\]

\( (R^2 = 0.88) \)

Figure 6. The non-dimensional relationship between energy dissipation and the porosity of gravel sample used to total length of the gabion weir.
The relation between the predicted and measured values of energy dissipation can be represented and plotted as followed by [9], [14], [16], and [23] as in figures 7a. and 7b. for both 2nd and 4th lengths of the gabion weir. According to these figures, a good agreement has been achieved between these values. The percentage of errors for both values of energy dissipation, measured and predicted, was calculated by equation (10) with an average value of 7.2335% as compared with [18] :

\[ E\% = \frac{(\Delta E/L)_{\text{predicted}} - (\Delta E/L)_{\text{measured}}}{(\Delta E/L)_{\text{predicted}}} \] (10)

Figures 7a and 7b. The relation between the predicted and measured values of energy dissipation of the 2nd length, (on the right side), and the 4th length (on the left side) of the gabion weir.

5. Conclusions
In the present study, the energy dissipation of the stepped gabion weir of three steps has been investigated by studying the factors affecting the dissipated energy by this hydraulic structure. Within the limitations of this study, it has been concluded that :

1- The dissipated energy of flow increases by increasing the discharge.
2- Increasing the ratio of length of the third step of the weir to its total length decreases the energy dissipation of flow, in general form.
3- The energy dissipation increases by decreasing the equivalent diameter of the used gravel sample.
4- The porosity has a slight inverse proportion on the dissipated energy of flow.
5- A general formula has been created for energy dissipation, and a good agreement for comparison between measured and predicted values of energy dissipation has been achieved with a percentage of errors with average value of 7.2335%.

Acknowledgements - The authors thank all supporters who assisted in completion of this study, especially the chief and staff members of Laboratory of fluid Mechanics in the University of Babylon, Iraq.
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