Dissipation of Energy of Flow by Conventional Type of Gabion Weir

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Abstract: The present study aimed to investigate the effect of using the conventional (rectangular) shape of gabion weir in dissipating the energy of flow. For that a series of laboratory tests (25 experiments and 194 test runs) were conducted on the gabion weir by using of a laboratory flume of 12 m long by a cross section of 0.3 m width, and 0.5 m height to test five different lengths of the weir, (40 cm, 60 cm, 80 cm, 100 cm, and 120 cm), with five respective monosized samples of natural quarry gravel with diameters (9.5-14) mm, (14-19) mm, (19-25) mm, (25-37.5) mm, and (37.5-50) mm. The tests were conducted for a range of discharge (0.7-15.0) l/s. Dimensionless analysis was used to analyze the data by using Buckingham Pi-Theorem to find the relation between the difference in energy of gabion ends and the unit discharge.

1. Introduction

Weirs consider as one of the hydraulic structures that can widely used in water works such as energy dissipation, regulation and control of water, flood mitigation, etc. Weirs differ according to the material which the body of the weir made from. Some of them have a solid body constructed from an impervious material such as concrete, while other types have a pervious body constructed from non-cohesive agglomerations of natural or broken particles such as rockfill. The weir type that has porous body constructed from pervious material contained in a metal mesh call as "gabion weir". Gabion weirs are structures having a stable texture, flexible nature, and easy way to build. This way illustrates by using a porous medium, such as rockfill, as filling material to form the body of the weir and putting it in a mesh grid. Many studies were carried out on the weir with different types and materials to discuss multi-subjects, and multi-situations in each subject. Some of these studies were deal with the effect of this type of hydraulic structures on the hydraulic characteristics of flow in different states such as, the behaviour of stepped chutes in transition-flow situation [1], the behaviour of stepped spillways in through-flow state [2], the seepage of flow through rockfill structures, and its theoretical solution during overtopping-flow condition [3], the attitude of permeable rubble mound river structures in cases of determination of discharge, and evaluation of flow behaviour through and around the body of the structure [4], [5], and the effect of broad-crested weir on design of hydraulic control structures and their measurements by varying the weir side slopes [6]. While other studies took in consider the behaviour of the pervious weir on energy dissipation, and the energy losses through it or on both of it sides such as, the energy loss through stepped gabion spillways [7], the gabion weir as energy dissipater with through and over-flow conditions [8], [9], [10], and [11], where it was concluded generally that the gabion weirs...
in stepped shape are good dissipaters of energy of flow with range of (25% - 85%) distributed unequally between the through-flow, and the over-flow conditions, where the through-flow have (80% - 85%) of the later percentage, and the rest is for over-flow. This goodness is up to 3 steps, but the total energy dissipation decreases with more steps. Besides that, the energy dissipation is inversely proportional with the depth of critical flow over the gabion weir, and the slope of step has no change on energy dissipation amount. The present study aims to investigate the dissipated amount of energy by using of the conventional, rectangular, type of the gabion weir.

2. Laboratory Work

In this study, twenty five laboratory experiments were carried out on five physical models by using five different gravel samples with each physical model. The total number of test runs was one hundred and ninety four test runs, and every physical model graphically named as configuration. The physical models used were fabricated from steel rods rapped with a grid sheet with an opening less than the size of the filling material to form the gabion basket then filled with the gravel material. Figure 1 shows definition sketch of the physical models and Table 1 presents the dimension of these models. The gravel samples used were five monosized gravel samples taken from the typical stone quarry of region of Bahr AnNajaf in AnNajaf Governorate, graded according to the American Society of Testing and Materials, ASTM, and numbered as gravel sample number1, gravel sample number2, gravel sample number3, gravel sample number4, and gravel sample number5 respectively. Table 2 presents the details of the used gravel samples in this study, and the value of porosity for each one of them. The laboratory flume used in this study was a glass sides tilting flume with dimensions of 12 m long by cross section of 0.3 m wide with 0.5 m height. The flume had a slope of (+0.006) during the test runs. The discharge was measured in the flume by two ways, the first way was by using a flow-meter device, and the other was the volumetric way, the second way used to verify the readings of the flow-meter. The discharge values were in range of (0.7-15.0) l/s. Carrying out the test runs illustrated firstly by stabilizing the physical model of gabion weir inside the flume, filling the model with the gravel, covering the model, and operating the flume pump.

![Figure 1. The physical models used in this study.](image-url)
| Physical model number, (Configuration number) | Physical model dimensions |  
|---------------------------------------------|---------------------------|
|                                            | Height, H (cm) | Length, L (cm) | Width, W (cm) |
| 1                                          | 40            | 40            | 30            |
| 2                                          | 40            | 60            | 30            |
| 3                                          | 40            | 80            | 30            |
| 4                                          | 40            | 100           | 30            |
| 5                                          | 40            | 120           | 30            |

| Gravel Sample No. | Diameter of used gravel sample, (mm) | Porosity, n |
|-------------------|--------------------------------------|-------------|
| 1                 | 9.5 – 14.0                           | 48.8        |
| 2                 | 14.0 – 19.0                          | 51.6        |
| 3                 | 19.0 – 25.0                          | 52.3        |
| 4                 | 25.0 – 37.5                          | 52.8        |
| 5                 | 37.5 – 50.0                          | 53.5        |

Secondly by measuring the discharge for the flow, depths of water upstream and downstream the model, the Phreatic line of water through the model, and finally by repeating the steps above for seven times after reaching the study state of the flow.

### 3. Dimensional Analysis

Generally, energy dissipation depends on hydraulic and geometric variables. For the rectangular shape of gabion weir, these variables can be expressed functionally as:

\[ f \{ q, y_u, y_1, y_2, LT, dm, \rho, g, n, i_s \} = 0 \]  

(1)

Where \( q \) is discharge per unit width measured by square length unit per time unit, (L²/T), \( y_u \) is the depth of water at the upstream side of gabion weir (L), \( y_1\) and \( y_2 \) are the depths of water at downstream side of gabion weir before and after the hydraulic jump respectively (L), LT is the gabion weir length (L), \( dm \) is the equivalent diameter of the used gravel sample (L), \( g \) is the gravitational acceleration (L/T²), \( \rho \) is Mass density (M/L³), \( n \) is porosity of the used gravel samples, and \( i_s \) is the slope of the laboratory flume. The energy at the upstream side of gabion weir was calculated by equation (2):

\[ E_u = Z_u + y_u + \left( \frac{v_u^2}{2g} \right) = Z_u + y_u + \left( \frac{q^2}{2gy_u^2} \right) \]  

(2)

Where \( E_u \) is the energy at the upstream side of gabion weir (L), \( Z_u \) is the elevation head (L), and \( v_u \) is the velocity of flow at the upstream side of gabion weir (L/T). While, the energy at the downstream side of gabion weir was calculated by equation (3):

\[ E_l = y_l + \left( \frac{v_l^2}{2g} \right) = y_l + \left( \frac{q^2}{2gy_l^2} \right) \]  

(3)

Where \( E_l \) is the energy at the downstream side of gabion weir (L), and \( v_l \) is the velocity of flow at the downstream side of gabion weir (L/T). The difference in energy between the upstream and downstream sides of gabion weir, \( \Delta E \), was calculated by equation (4):

...
\[ \Delta E = E_u - E_l \] (4)

From equations (2), (3), and (4), it can be noticed that \( E_u \) depends on \( Z_u \) and \( y_u \), \( Z_u \) depends on the slope of the laboratory flume, \( i_s \), and \( E_l \) depends on \( y_1 \). So, equation (1) can be re-written as:

\[ f\{q, \Delta E, LT, dm, \rho, g, n\} = 0 \] (5)

By using of dimensional analysis (Buckingham Pi – Theorem), variables of equation (5) can be expressed by non-dimensional parameters as follows:

\[ \frac{\Delta E}{LT} = f\{(dm/LT), (q/g^{0.5}.LT^{1.5}), n\} \] (6)

4. Results and Discussion

The In order to represent the relationship between the discharge and the energy dissipation, a non-dimensional data set was used. The dimensionless parameter \( (q^g(g^{0.5}.LT^{1.5})^{-1}) \) was used for discharge representation, and the parameter \( (\Delta E/LT) \) was used for representation of energy dissipation. Accordingly, the relationship above will be written as:

\[ (\Delta E/LT) = f\{g^q(g^{0.5}.LT^{1.5})^{-1}\} \] (7)

By using of "Microsoft – Excel" computer program, it was found that the best form of equation of trend line which represents the relationship between energy dissipation dimensionless parameter, \( (\Delta E/LT) \), and unit discharge dimensionless parameter, \( (q^g(g^{0.5}.LT^{1.5})^{-1}) \) was the power form. Accordingly, equation (7) becomes:

\[ \Delta E/LT = c_1 \{q^g(g^{0.5}.LT^{1.5})^{-1}\}^{k_1} \] (8)

Where \( c_1 \) and \( k_1 \) are constants. Figures 2, 3, 4, 5, and 6 show the variation of values of energy dissipation dimensionless parameter with values of unit discharge dimensionless parameter for all test runs carried out in this study. In these figures the values of energy dissipation dimensionless parameter is directly proportional with the values of unit discharge dimensionless parameter, and values of former decreases by increasing the dm.

Tables 3, 4, 5, 6, and 7 respectively present the values of constants \( c_1 \) and \( k_1 \) of energy dissipation dimensionless parameter-unit discharge dimensionless parameter relationship for configurations of this study.

Tables 8, 9, 10, 11, and 12 respectively summarize the values of difference in energy \( \Delta E \) at minimum 0.7 l/s, and 3.6 l/s applied discharges where the discharge of 3.6 l/s was selected for comparison purposes. In these values \( \Delta E \) at the minimum applied discharge was varied between 0.024 m and 0.225 m, and \( \Delta E \) at 3.6 l/s applied discharge was varied between 0.112 m and 0.331 m. The latter group of tables show that generally the values of \( \Delta E \) at the minimum and 3.6 l/s applied discharges decrease by increasing the value of dm. While the values of \( \Delta E \) at the minimum and 3.6 l/s applied discharges increase by increasing the length of the gabion weir.

By using of multi-linear regression for the data set to correlate the dependent parameters with other independent ones, [12], [13], [14], [15], [16], [17], [18], [19], and [20], equation (6) can be re-written as:

\[ \Delta E = 1.0538 \times 10^{12} \{q^{0.6387}.LT^{0.1629}(dm^{0.1210}.g^{0.3194}.n^{6.6063})^{-1}\} \] \[ R^2 = 0.92 \] (9)
Figure 2. Variation of energy dissipation dimensionless parameter values with unit discharge dimensionless parameter values for tests runs of configuration number 1.

Figure 3. Variation of energy dissipation dimensionless parameter values with unit discharge dimensionless parameter values for tests runs of configuration number 2.

Figure 4. Variation of energy dissipation dimensionless parameter values with unit discharge dimensionless parameter values for tests runs of configuration number 3.
Figure 5. Variation of energy dissipation dimensionless parameter values with unit discharge dimensionless parameter values for tests runs of configuration number 4.

Figure 6. Variation of energy dissipation dimensionless parameter values with unit discharge dimensionless parameter values for tests runs of configuration number 5.

Table 3. Values of $c_1$, $k_1$, and $R^2$ of trend line equation of energy dissipation dimensionless parameter – unit discharge dimensionless parameter relationship for configuration number 1.

| dm (mm) | $c_1$   | $k_1$   | $R^2$ |
|---------|---------|---------|-------|
| 9.5-14  | 2.6152  | 0.2418  | 0.87  |
| 14-19   | 7.0435  | 0.6230  | 0.99  |
| 19-25   | 6.5543  | 0.6581  | 0.98  |
| 25-37.5 | 6.0787  | 0.6632  | 0.99  |
| 37.5-50 | 4.3063  | 0.5949  | 0.99  |

Table 4. Values of $c_1$, $k_1$, and $R^2$ of trend line equation of energy dissipation dimensionless parameter – unit discharge dimensionless parameter relationship for configuration number 2.

| dm (mm) | $c_1$   | $k_1$   | $R^2$ |
|---------|---------|---------|-------|
| 9.5-14  | 6.2872  | 0.5319  | 0.97  |
| 14-19   | 10.249  | 0.6867  | 0.99  |
| 19-25   | 6.7195  | 0.6507  | 0.95  |
| 25-37.5 | 6.7451  | 0.6521  | 1.00  |
| 37.5-50 | 6.9118  | 0.6991  | 0.99  |
Table 5. Values of $c_1$, $k_1$, and $R^2$ of trend line equation of energy dissipation dimensionless parameter – unit discharge dimensionless parameter relationship for configuration number 3.

| dm (mm) | $c_1$   | $k_1$   | $R^2$ |
|---------|---------|---------|-------|
| 9.5-14  | 7.4574  | 0.5862  | 0.98  |
| 14-19   | 10.882  | 0.6825  | 0.98  |
| 19-25   | 6.8343  | 0.6190  | 0.99  |
| 25-37.5 | 6.6507  | 0.6374  | 1.00  |
| 37.5-50 | 5.1675  | 0.6101  | 0.99  |

Table 6. Values of $c_1$, $k_1$, and $R^2$ of trend line equation of energy dissipation dimensionless parameter – unit discharge dimensionless parameter relationship for configuration number 4.

| dm (mm) | $c_1$   | $k_1$   | $R^2$ |
|---------|---------|---------|-------|
| 9.5-14  | 4.5409  | 0.4740  | 0.90  |
| 14-19   | 8.4444  | 0.6080  | 0.98  |
| 19-25   | 6.1932  | 0.5973  | 0.99  |
| 25-37.5 | 6.6308  | 0.6316  | 0.99  |
| 37.5-50 | 5.7588  | 0.6253  | 1.00  |

Table 7. Values of $c_1$, $k_1$, and $R^2$ of trend line equation of energy dissipation dimensionless parameter – unit discharge dimensionless parameter relationship for configuration number 5.

| dm (mm) | $c_1$   | $k_1$   | $R^2$ |
|---------|---------|---------|-------|
| 9.5-14  | 16.259  | 0.7345  | 0.94  |
| 14-19   | 5.3307  | 0.5449  | 0.99  |
| 19-25   | 23.0600 | 0.8325  | 0.98  |
| 25-37.5 | 15.885  | 0.7783  | 0.98  |
| 37.5-50 | 37.630  | 0.9830  | 0.96  |

Table 8. Values of $\Delta E$ at minimum and 3.6 l/s applied discharges measured for configuration number 1.

| dm (mm) | $\Delta E$ at minimum applied discharge (m) | $\Delta E$ at 3.6 l/s applied discharge (m) |
|---------|--------------------------------------------|-------------------------------------------|
| 9.5-14  | 0.225                                      |                                           |
| 14-19   | 0.077                                      | 0.179                                     |
| 19-25   | 0.058                                      | 0.160                                     |
| 25-37.5 | 0.055                                      | 0.145                                     |
| 37.5-50 | 0.055                                      | 0.135                                     |

Table 9. Values of $\Delta E$ at minimum and 3.6 l/s applied discharges measured for configuration number 2.

| dm (mm) | $\Delta E$ at minimum applied discharge (m) | $\Delta E$ at 3.6 l/s applied discharge (m) |
|---------|--------------------------------------------|-------------------------------------------|
| 9.5-14  | 0.107                                      | 0.284                                     |
| 14-19   | 0.088                                      | 0.235                                     |
| 19-25   | 0.070                                      | 0.184                                     |
| 25-37.5 | 0.055                                      | 0.165                                     |
| 37.5-50 | 0.051                                      | 0.134                                     |
Table 10. Values of ΔE at minimum and 3.6 l/s applied discharges measured for configuration number 3.

| dm (mm) | ΔE at minimum applied discharge (m) | ΔE at 3.6 l/s applied discharge (m) |
|---------|-----------------------------------|-----------------------------------|
| 9.5-14  | 0.095                             | 0.266                             |
| 14-19   | 0.071                             | 0.236                             |
| 19-25   | 0.074                             | 0.214                             |
| 25-37.5 | 0.069                             | 0.179                             |
| 37.5-50 | 0.064                             | 0.163                             |

Table 11. Values of ΔE at minimum and 3.6 l/s applied discharges measured for configuration number 4.

| dm (mm) | ΔE at minimum applied discharge (m) | ΔE at 3.6 l/s applied discharge (m) |
|---------|-----------------------------------|-----------------------------------|
| 9.5-14  | 0.119                             | 0.331                             |
| 14-19   | 0.094                             | 0.275                             |
| 19-25   | 0.076                             | 0.230                             |
| 25-37.5 | 0.067                             | 0.195                             |
| 37.5-50 | 0.066                             | 0.168                             |

Table 12. Values of ΔE at minimum and 3.6 l/s applied discharges measured for configuration number 5.

| dm (mm) | ΔE at minimum applied discharge (m) | ΔE at 3.6 l/s applied discharge (m) |
|---------|-----------------------------------|-----------------------------------|
| 9.5-14  | 0.094                             | 0.308                             |
| 14-19   | 0.104                             | 0.297                             |
| 19-25   | 0.049                             | 0.262                             |
| 25-37.5 | 0.053                             | 0.224                             |
| 37.5-50 | 0.024                             | 0.112                             |

5. Conclusion
The flow of water through and over rockfill materials is a wide important subject, especially in management of water resources and as an ecological friendly solution in various domains. Due to the porous nature of the gabion weirs, it allow the migration of some aquatic lives in the water path that leads to preservation of the water environment. Within the limitations of this study, it have been concluded that:

1- the dimensionless equation is possible to use for design purposes.
2- the energy dissipation is directly proportional with unit discharge.
3- the energy dissipation decreases with the increase of the equivalent diameter of the used gravel sample.
4- at the same gravel sample and discharge, the value of energy dissipation increases by increasing the length of the gabion weir.

References
[1] Chanson H and Toombes L 2004 Hydraulics of stepped chutes: the transition flow J. Hydr. Res. 24 43-54.
[2] Kazemi-Nasaban Gh 1996 Flow characteristics through gabion stepped spillways M. Eng. Thesis (Shahid - Chamran University – Ahwaz - Iran).
[3] Li B and Garga V K 1998 Theoretical solution for seepage flow in overtopped rockfill J. Hydraul. Eng. 124 213-217.
[4] Michioku K, Maeno S, Furusawa T and Haneda M 2005 Discharge through a permeable rubble mound weir J. Hydraul. Eng. 131 1-10.
[5] Michioku K, Takehara K and Etoh T 2007 An experimental study on flow field in and around rubble mound river structures Journal of Hydro-Science and Hydraulics 25 37-45.
[6] Sargison J E and Percy A 2009 Hydraulics of broad-crested weirs with varying side slopes J. Irrig. Drain Eng. 135 115-118.
[7] Chinnarasri Ch 2003 Energy loss through stepped gabion spillways Proc. Energy Technology Toward a Clean Environment 2nd Regional Conf. pp 436-441.
[8] Chanson H 2001 Hydraulic design of stepped spillway and downstream energy dissipaters Dam Engineering 11 205-242.
[9] Salmasi F, Taghi-Sattari M and Mahesh-Pal 2012 Application of data mining on evaluation of energy dissipation over low gabion-stepped weir Turk. J. Agric. 36 95-106.
[10] Kells J A 1994 Energy dissipation at a gabion weir with through and over flow Can. Soc. Civ. Eng. Annul. Conf. pp 26-35.
[11] Peyras L, Royet P and Degoutte G 1992 Flow and energy dissipation over stepped gabion weirs J. Hydraul. Eng. 118 707-717.
[12] Azizi A, Meftah-Halghie M, Ahmed M Z and Golmayie S A 2008 Evaluation the affection of used material porosity on energy dissipation in gabion stepped weirs J. Agric. Sci. Natur. Resour. 15 1.
[13] Vashisth A 2017 Energy dissipation over stepped gabion weir International Journal of Dynamics of Fluids 13 153-159.
[14] Stephenson D 1979 Gabion weir energy dissipaters in Proc. Congress 13th ICOLD q50 r3 pp 33-43.
[15] Kang J, Kim S, Yeo H and Lee N 2014 Experimental study on flow characteristic in sloping weir Engineering 6 329-337.
[16] Ashour M A, Sayed T and El-Attar S 2014 A new water energy dissipater for efficient energy dissipation and enriching the flow with dissolved oxygen content Limnol. Rev. 14 3-11.
[17] Ashour M A, Sayed T and El-Attar S 2015 Impact of curved shaped energy dissipaters downstream diversion head structures to the dissolved oxygen content in irrigation canals and enhancement of irrigation water quality International Journal of Scientific Research and Innovative Technology 2 14-26.
[18] Shafai-Bajestan M and Kazemi-Nasaban Gh 2011 Experimental study on gabion stepped spillway Experimental Methods in Hydraulic Research, Geoplanet : Earth and Planetary Science, pp 267-274.
[19] Gupta S K, Mehta R C and Dwivedi V K 2012 Modelling of relative length and relative energy loss of free hydraulic jump in horizontal prismatic channel Proc. Nirma University 3rd Int. Conf. vol 1 pp 529-537.
[20] Moussa Y A, Ali A M and Saleh Y K 2016 Performance of Sills Over Aprons under The Effect of Submerged Hydraulic Jump, ( Case Study : Naga Hammadi Barrage ) Ain Shams Eng J 9 (Preprint 10.1016).

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