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Laboratory Study of the Effects of Step Number, Slope and Particle Size on Energy Dissipation in Gabion Stepped Weirs

S. Razi, F. Salmasi*, A. Hoseinzade Dalir

Department of water engineering, University of Tabriz, Tabriz, Iran

ABSTRACT: Gabion stepped weir is a simple hydraulic and environment friendly structure that can be used to dissipate flow energy in downstream of dams or to control downstream erosion of various structures. Most researches have been related to concrete and rigid stepped spillways, so studies on gabion stepped weirs are very small. In this research, using the experimental method and physical model, various components that affected the energy loss in gabion stepped weirs were studied and comparisons with other studies by researchers were also made. The flow passes in gabion stepped weir was carried out both in overflow and inflow (both simultaneously) and the amount of energy dissipation along the structure was calculated based on the energy relation. In this study, completely uniform particles with three diameters (d_{50}) of 10, 25 and 40 mm were used. The height and width of physical models made of gabion stepped weirs were 60 cm and 40 cm respectively, with stairs of 3, 6 and 12 and height of stairs 5, 10 and 20 cm and the slope of the weirs are 1:1, 1:2 and 1:3 (2 and 3 horizontals, 1 vertical). In the gabion stepped weirs, the downward slope of the weir had a negligible impact on the energy dissipation. As the number of steps increased (for constant h/l), the energy loss was decreased. The average diameter of the particles of 10 mm for $y_0/H_w<0.92$ and the average diameter of the particles of 40 mm for $y_0/H_w>0.92$ had the highest of relative energy loss. Due to the fact that the stone materials used in this research are of a broken type, it is recommended that further research be carried out on round stone materials.

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1- Introduction

Gabion overflows are widely used in construction projects, especially in catchment areas, to control the erosion of floods and also to raise water levels in order to dewatering in irrigation canals. Most of the previous studies have been conducted on rigid impervious weirs, while the permeable type known as gabion has some advantages. One of the advantages of these weirs is the ease of implementation, the use of loan materials, sustainability, flexibility and high permeability, cost-effectiveness and, most importantly, environmental compatibility [1]. These types of weirs are more flexible than the rigid ones and are resistant to the stresses caused by water pressure. The depreciation of the flow energy from such structures is high due to the existence of flow through the passage of the stairs and thus the cost of building the calm pond is reduces [2]. In general, solid concrete weirs have been used, but nowadays alternative structures made of loose stones such as gabion weir are preferred since the latter can better meet natural and ecological requirements. From the viewpoint of water quality, physical and chemical substances such as sediments and suspended organic matter can pass downstream through the permeable body. This eventually minimizes sedimentation and eutrophication in an impoundment. Between the stones, bacteria inhabiting the granular surface may decompose organic matter. This biochemical reaction contributes to the purification of river or canal water as it flows through the stones, just like in water purification and sewage water plants. It is also expected that turbulence generated in the granular media will promote aeration through the air-water interface helping in the aerobic decomposition of organic matter. In these respects, the gabion weir might be a structure with minimal negative impact on the water environment and is considered to be more environmentally friendly than most of the recently constructed impermeable weirs [3]. Most of the research has so far been related to stairs of large concrete dams or rigid stepped spillways. Since overflow and inflow has so far been neglected, this is a valuable subject for future study [4].

Salmasi et al. (2012) used eight physical models of gabion stepped weir with porosities of 38, 40 and 42%, and slopes 1:1 and 1:2. In that study, the steps were provided with and without coating. They showed that in the smallest flow discharge for impermeable step overflow, the energy loss is lower. They also showed that steps with impenetrable vertical surfaces had a greater energy loss than horizontal portions, and with increasing porosity and slope reduction, more energy was dissipated [2].

Corresponding author, E-mail: salmasi@tabrizu.ac.ir

Zare and Doering (2012) conducted their experiments on round stepped weirs and ordinary stepped weirs, and concluded that the rounded stepped weirs dissipate flow energy by 3% more than ordinary stepped weirs [5]. Aal et al. (2017) conducted physical experiments to repair energy losses in stepped spillways using a breaker at the University of Zagazig, Egypt. They considered six modes of breakers. The first case of stepped spillway was without a breaker and the subsequent state of the breaker and ratios (height of the breaker to step height) were 0.2, 0.4, 0.6, 0.8 and 1. The results showed that the use of a breaker led to an increase in energy loss and the maximum energy loss in a breaker was 0.8 [6]. Khatibi et al. (2014) conducted the energy dissipation over stepped-gabion weirs using a series of laboratory experiments, building models to clarify the experimental data. They provided the multiple regression equations based on dimensional analysis concept, ANNs and GEP for modeling the energy dissipation over stepped gabion weirs. Results provided that regression approach can be also used for modeling of the energy dissipation [7].

The purpose of this study was investigation of the hydraulic of flow over the stepped weirs, effect of the size of the stone particles used in the structure, effect of the number of steps and slopes of the downstream structure on energy dissipation. Finally, this study tends to introduce the optimum physical model of the stepped gabion weirs to achieve the maximum energy loss with the least cost.

2- Material and methods

The experiments were carried out at the Hydraulic Laboratory of the University of Tabriz, department of water engineering. According to Figure 1, experiments were carried out on a horizontal metal flume of 10 meters long, 0.4 meter wide. The floor of the flume was made up of galvanized iron and its walls were of glass thickness of 10 mm. In this study, completely uniform stone particles with three diameters (d50) of 10, 25 and 40 mm were used. For measuring the depth of water, an electronic point gauge with a frequency of 20 Hz and a precision of 12 bits were used.

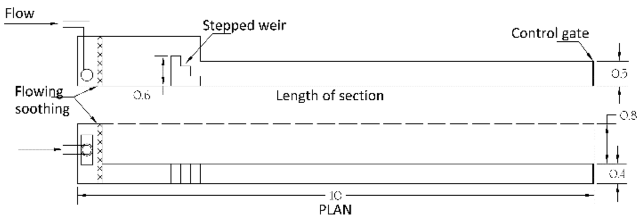

Figure 1. A view of the laboratory flume and the location of the stepped weir

Height and width of physical models was 60 and 40 cm respectively, with 3, 6 and 12 steps. The height of steps was 5, 10 and 20 cm and the slope of weirs were selected 1:1, 1:2 and 1:3 (2 and 3 horizontals, 1 vertical).

3- Theory and dimensional analysis

In this research, dimensional analyzes were done based on the Buckingham theorem. The effective parameters in dimensional analysis can be written as follows

$$f\left(H_w, d_{50}, q, \mathrm{N}, \mathrm{h}, \mathrm{g}, \mathrm{y}, E_0, E_0 - E_1 = \Delta E\right) = 0 \quad (1)$$

After simplification, the following dimensionless parameters are obtained:

$$f\left(\frac{y}{N.h}, \frac{d_{50}}{y}, \frac{\Delta E}{E_0}, \frac{y}{H_w}, \frac{V}{\sqrt{gH_w}}, \frac{q^2}{gH_w{}^3}\right) = 0 \quad (2)$$

The amount of energy dissipation is based on the specific energy in the weir upstream and downstream and can be calculated from Equation 3:

$$\Delta E = E_0 - E_1 \quad (3)$$

4- Results and discussion

Figure 2 shows one of the gabion stepped weir used in this study. Flow over the weir was in transitional regime and water was aerated due to turbulence.

Figure 2. Transitional flow in a weir with 6 steps and slope of 1:2, Q=44 lit/s, d_{50}=40 mm

In Figure 3, the dimensionless variation of the energy flux versus the relative critical depth is plotted for the weir of 3, 6, and 12 steps with an average diameter of 40 mm stone particles in gabion and with slope of 1:1.

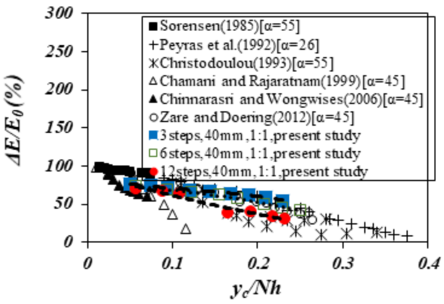

Figure 3. Relative energy loss and relative critical depth with number of steps and comparison with other studies

As shown in Figure 3, in the gabion stepped weirs, with increasing number of steps, the relative energy loss was decreased due to the decrease in the contact surface of the structure with water and the decrease in the flow resistance and also the rapid formation skimming flow. The results of this study were a good agreement with the results of Zare and Doering (2012), Christodoulou (1993) and Peyras et al. (1992). Since the research by Peyras et al.

(1992) on the gabion stepped weir and used stone particles were in the range of 30 to 45 millimeters, there was a better agreement with the results of this study [5, 8, 9].

In Figure 4, changes in energy loss respect to discharge has a nonlinear trend. Comparison with the results of the Kells (1994) and Peyrs et al. (1992) [9, 10] demonstrated proper agreements.

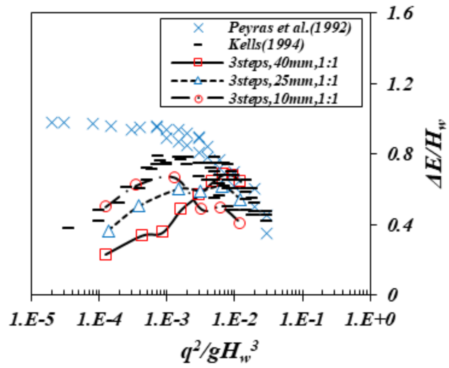

Figure 4. Variation in relative energy loss versus relative discharge for different stone sizes

According to Figure 4 in gabion weirs the energy loss increased as the flow rate was increased. But from a given amount of flow, the energy loss was decreased, although this upward and downward trend depends on the average diameter of the stone particles used in the experiments. In other words, the declining trend of relative energy loss in medium particles diameter was faster than large particles diameter.

In order to further investigation of the effect of particles size on the energy loss, changes in the energy loss versus the depth of water behind the structure (y_0) is presented according to Figure 5.

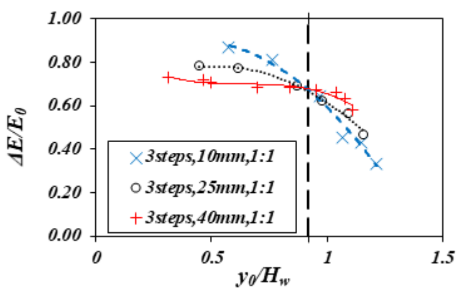

Figure 5. Changes in energy loss against the depth of water behind the weir

Therefore, with reference to Figure 5, it can be expected that the proposed scheme (Figure 6), in which the fine particles inside the structural body and coarse particles were used on the steps, it can be the most efficient in depleting current energy.

As shown in Figure 7, for a mean diameter of 40 mm, the decrease in weir slope has not shown much effect on relative energy loss. Kells (1994) also concluded this result, which tested the two slopes 1:1 and 1:2. But for a mean diameter of 10 mm, a decrease in the weir slope from 1:1 to 1:3 showed a relatively greater effect on relative energy loss.

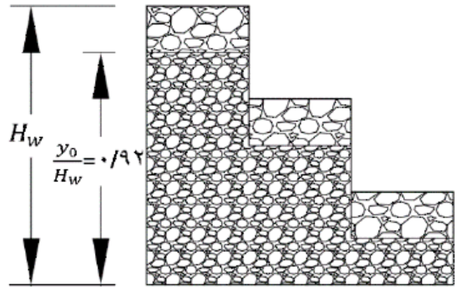

Figure 6. The proposed view of the gabion stepped weir with fine particles inside the body and the coarse particles on the steps

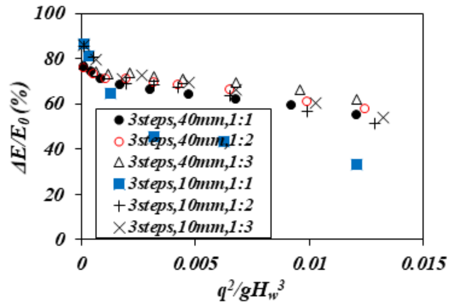

Figure 7. Changes in energy loss versus discharge for different modes of weir

5- Conclusion

Energy loss of flow was a function of the intensity of flow, the average diameter of the stone particles in gabion basket, the number of steps, the height and slope of the weir. In other words, by increasing the flow rate, the depth and flow velocity in downstream of weir were also increased, and consequently, the flow loss was decreased. On the other hand, with the increase in the number of weir steps, the relative energy loss was decreased. Therefore, it was recommended to use weir with 3 steps in executive works. The slope of the gabion structures had little effect on the energy loss. The average diameter of stone particles (10 mm) for $y_0/H_w<0.92$ and the average diameter of particles (40 mm) for $y_0/H_w>0.92$ had the highest relative energy loss.

References

[1] C. Chinnarasri, S. Donjadee, U. Israngkura, Hydraulic characteristics of gabion-stepped weirs, Journal of Hydraulic Engineering, 134(8) (2008) 1147-1152.

[2] F. Salmasi, M. Chamani, D. Farsadi Zadeh, Experimental study of energy dissipation over stepped gabion spillways with low heights, Iranian Journal of Science and Technology. Transactions of Civil Engineering, 36(C2) (2012) 253.

[3] H.I. Mohamed, Flow over gabion weirs, Journal of Irrigation and Drainage Engineering, 136(8) (2009) 573-577.

[4] C.A. Gonzalez, M. Takahashi, H. Chanson, An experimental study of effects of step roughness in skimming flows on stepped chutes, Journal of Hydraulic Research, 46(sup1) (2008) 24-35.

[5] H.K. Zare, J.C. Doering, Effect of rounding edges of stepped spillways on the flow characteristics, Canadian Journal of Civil Engineering, 39(2) (2012) 140-153.

[6] G.M.A. Aal, M. Sobeah, E. Helal, M. El-Fooly, Improving energy dissipation on stepped spillways using breakers, Ain Shams Engineering Journal, (2017).

[7] R Khatibi, F Salmasi, MA Ghorbani, H Asadi, Modelling energy dissipation over stepped-gabion weirs by artificial intelligence, Water Resour Manag, 28 (2014)1807–1821. doi: 10.1007/s11269-014-0545-y.

[8] G.C. Christodoulou, Energy dissipation on stepped spillways, Journal of Hydraulic Engineering, 119(5) (1993) 644-650.

[9] L.A. Peyras, P. Royet, G. Degoutte, Flow and energy dissipation over stepped gabion weirs, Journal of Hydraulic Engineering, 118(5) (1992) 707-717.

[10] J. Kells, Energy dissipation at a gabion weir with throughflow and overflow, in: Ann. Conference Can. Soc. Civ. Engrg., Winnipeg, Canada, June, 1994, pp. 1-4.

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