Investigation of Energy Dissipation in Gabion Stepped Weirs

Mohammed A. Almajeed A. Alabas[1,2*], **Riyadh Al-Ameri**[2], **Lloyd Chua**[2], **Subrat Das**[2]

[1] *Babylon University, Babylon, IRAQ*
[2] *Deakin University, Victoria, AUSTRALIA*

Keywords: Gabion weir, Energy dissipation, Stepped weir, Inclined steps, End sill steps.

Weirs are widely used in hydraulic structures to control and regulate flow in open channels. Gabion weirs are frequently used in rivers, small dams, energy dissipaters, flood control works, and check dams, among other uses, and can be used to build a stepped weir. Dissipation of the energy (kinetic energy) on spillways or weirs is important to protect both hydraulic structures and downstream channels. This study aims to investigate the energy dissipation in gabion stepped weirs. For this purpose, six lab scale models of gabion stepped weirs each with six levels of impervious stepped weirs were investigated, which includes two downstream slopes (1:1 & 1:2, V:H) and three step face geometry (normal, end sill, and inclined steps). The rock fill material is crushed stone of nominal size (13.2 mm–19.0 mm), with a porosity of 0.42. Results showed that gabion weirs have more energy dissipation than impervious weirs around 20% at low discharge and only 3% at high discharge. Moreover, the step face geometry is more effective at medium discharge (nappe and transition flow regimes), while there is no effect at low and high discharge (through and skimming flow regimes). Finally, it was found that the energy dissipation increased with decreases in the downstream slope for all step configurations.

1. Introduction

Weirs are hydraulic structures widely used in water works such as energy dissipation, water regulation and control, flood mitigation, and other purposes. Weirs differ according to the material from which the body of the weir is made. Some 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 rock-fill. A weir type with a porous body constructed from pervious material is a gabion weir, whose structures have stability and flexibility. They are relatively easy to build, using a porous medium, such as rock-fill, as filling material in a mesh grid Salmasi, Chamani [1]. Generally, gabion weir structures are considered to be an economical alternative compared with other types, as the filling material used in body formation is the most abundant and economical material in hydraulic engineering practice.

Several studies were conducted to investigate the flow characteristics and energy dissipation on gabion weirs. Stephenson [2] estimated the energy dissipation on a rectangular and stepped gabion weirs. Different downstream slopes at V:H ratios of 1:1, 1:2, 1:3, and 2:3 with different numbers of steps (two, three, and four steps) were used. The results show that the energy dissipation increasing as the downstream weir slope decreased. Furthermore, the energy dissipation was increased as the number of steps increased for the first three steps, then decreased with increasing steps. Peyras, Royet [3] conducted an experimental study to investigate the energy dissipation over stepped gabion weirs. Three downstream slopes of 1:1, 1:2, and 1:3, with different numbers of steps (3, 4, and 5). Four step face geometry were used: plain gabions, plain gabions with a horizontal concrete, inclined gabions with a concrete slab, and rectangular gabion end sill steps. Results indicate that inclined and end sill steps had more energy dissipation than normal steps. Kells [4] point out that there was no clear effect for downstream slopes on the rate of energy dissipation. In addition, energy dissipation increased up to 20% when through-flow was allowed. Chinnarasri, Donjadee [5] showed that the gabion stepped weirs had more energy dissipation than horizontal stepped weirs, of 7%, 10%, and 14% for slopes 30°, 45°, and 60°, respectively. Moreover, the downstream slope had more effect on energy dissipation than the stone size and shape. Salmasi, Chamani [1] investigate the behaviour of gabion stepped weirs for energy dissipation. Results show that at low rate of flow, the dissipation of energy increased as increasing rock-fill porosity. Moreover, decreasing the downstream slope of the spillway produced more energy dissipation. Wuthrich and Chanson [6] studied the hydraulic performance of gabion stepped weirs. They demonstrated that at the high rates of discharges, the gabion stepped weirs had less energy dissipation than the impervious weirs, and this result may be a counterintuitive result Wuthrich and Chanson [6], Chanson [7]. In contrast, at low discharge, the stepped gabion weirs had a higher energy dissipation than the impervious weirs. In summary, several studies on gabion stepped weirs were conducted, but the results showed some differences, especially in terms of the effect of downstream slope on the energy dissipation, in addition to the lack of sufficient studies on the step face geometry and how to improve energy dissipation. The aim of present study is to investigate the energy dissipation on gabion and impervious stepped weir with different downstream slopes and step face geometry.

2. Experimental setup

The hydraulic flume of plexiglass side-wall has 500 cm length, 7.5 cm width, and 25 cm height as were used at the civil laboratory in school of engineering / Deakin university as shown in Figure (1). The water tank capacity was 250 litres with a pumping system of a maximum flow rate of 150 l/min. To control tail water depth and the hydraulic jump position, the flume was equipped with sluice gate at the downstream end. To measure flow rate, a digital flow meter was used with an accuracy of ± 3%. Pointer gauges with an accuracy of ± 0.1 mm were used to measure water depth at three positions: upstream of the weir, and downstream of the weir before and after the hydraulic jump.

Figure 1. Hydraulic flume details

Three steps, two downstream slopes (1:1, and 1:2) with three steps geometry (normal, inclined, and end sill) were used for gabion and impervious stepped weir. Crushed stone of nominal size (9.5 mm–19 mm) with porosity of 0.42 was used as a rock fill material. All models were designed to a scale of 1:20 and had the same height, width, step height, and broad crest (height 15 cm, width 7.5 cm, step height 5 cm, and broad crest 10 cm). The sketch of physical models was shown in Figure (2).

3. Energy dissipation:

The energy dissipation on the weir can be defined as the difference between the energy of water upstream and downstream of the weir. Figure (3) shows the positions of water depth measurements.

The total energy upstream the weir (Eo) can be calculated as follows:

$$Eo = Hw + \frac{3}{2}Yc \qquad (1)$$

Where (Hw) height of weir, and (Yc) critical depth above weir crest, which can be calculated as follows:

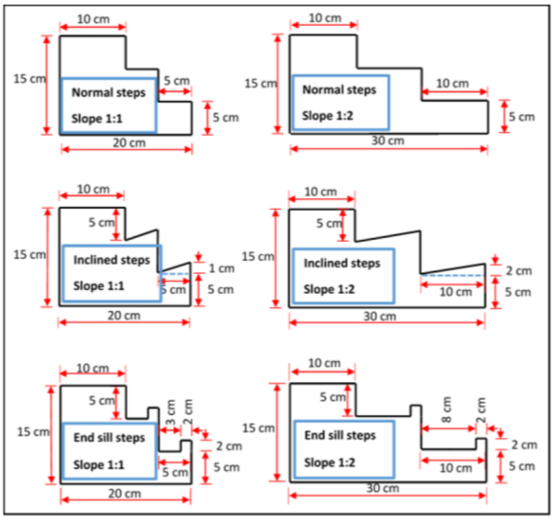

Figure 2. Sketch of physical models

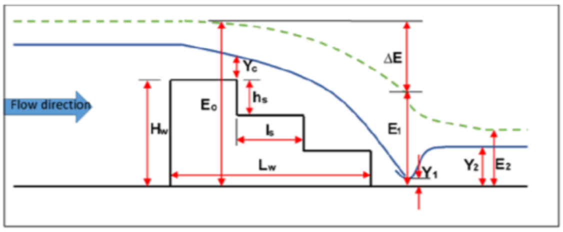

Figure 3. Typical weir section with flow parameters

$$Yc = \sqrt[3]{\frac{q^2}{2g}} \qquad (2)$$

Where (q) discharge per unit width, and (g) gravitational acceleration. The total energy downstream the weir (E_1) can be calculated as follows:

$$E_1 = Y_1 + \alpha \frac{{v_1}^2}{2g} \qquad (3)$$

Where (Y_1) water depth at the toe of the weir (V_1) the mean velocity at the toe of the weir, and(α) the correction coefficient of non-uniform velocity distribution.

According to Chow [8], α = (1.03-1.36) for small channels. For simplicity, several researchers such as Salmasi, Chamani [1], Stephenson [2], Peyras, Royet [3], Kells [4], Chinnarasri, Donjadee [5] used α = 1.

Due to flow conditions at the toe of weir (thin turbulence, and aerated flow), the measurement of flow depth is not accurate. Several researchers, such as Chinnarasri, Donjadee [5], Diez-Cascon, Blanco [9], Matos and Quinteia [10], Pegram, Officer [11], André and Schleiss [12], used the standard hydraulic jump formula to calculate the conjugate water depth as follows:

$$\frac{\Delta \mathrm{E}}{\mathrm{E}_0} = \frac{\mathrm{E}_0 - \mathrm{E}_1}{\mathrm{E}_0} \qquad (2)$$

Where (ΔE) the energy dissipation on the weir ($\Delta E = Eo - E1$).

4. Results and analysis

Figure (4) shows the energy dissipation on a gabion stepped weir for downstream slopes 1:1 and 1:2. With increasing the discharge, dissipation of energy decreases for all downstream slopes and step configurations. This finding agrees with previous studies such as Salmasi, Chamani [1], Peyras, Royet [3], Kells [4], Chinnarasri, Donjadee [5]. At low discharges, when the flow is through-flow, the rate of energy dissipation was the maximum due to high resistance to flow offering by the voids of rock fill materials. The energy dissipation rate ranged between 85% and 89% for the through flow, similar to results found by Kells [4]. The effect of step face geometry was not appeared because the overflow was not started at this stage. At medium discharge (nappe and transition flow regimes), the effect of step face geometry increased. The inclined steps and end sill steps have higher energy dissipation than normal steps, might be due to the high resistance of step face. On the other hand, at high discharge (skimming flow), the effect of step face geometry decreased because the water skimmed over the pseudo-bottom formed by outer edge of steps, not on step face and the effect of step face geometry reduced.

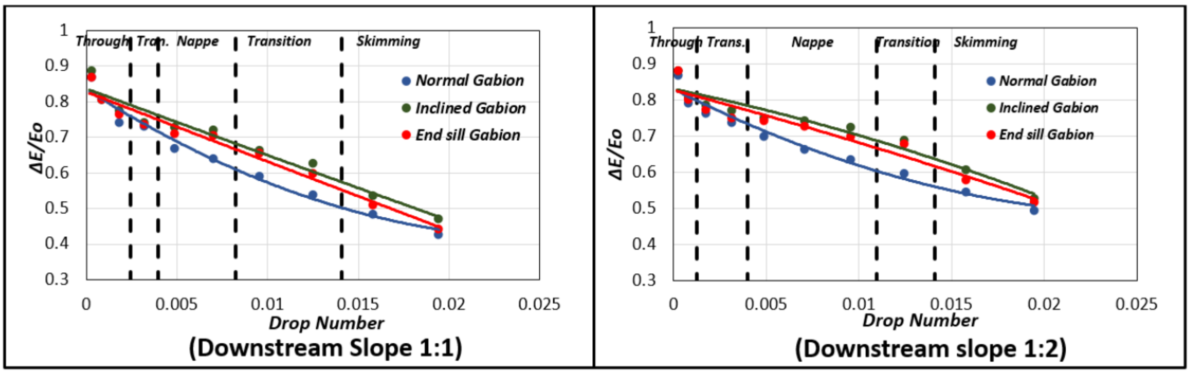

Figure 4. Energy dissipation on gabion stepped weir

The energy dissipation on gabion and impervious weirs for three step face geometries of normal, inclined, and end sill steps, and two downstream slopes of 1:1 and 1:2 is presented in Figure (5). It can be recognised that all curves had the same trend, where gabion weirs offered higher dissipation of energy than impervious weirs. At through-flow regime (low discharge) gabion weirs have more energy dissipation than impervious weirs within 17% for downstream slope 1:1 and 20% for downstream slope 1:2. With increasing the discharge the difference in energy dissipation between gabion and impervious weirs decreased because the effect of through-flow decreased. At the highest rates of flow (skimming flow regime), gabion have only 3% more energy dissipation than impervious weirs. Chinnarasri, Donjadee [5] stated that gabion weirs provided higher energy dissipation than impervious within 7% to 14% depending on downstream slope. Nevertheless, Wuthrich and Chanson [6] presented a counterintuitive result, where they reported that gabion stepped weirs have the lowest rate of energy dissipation.

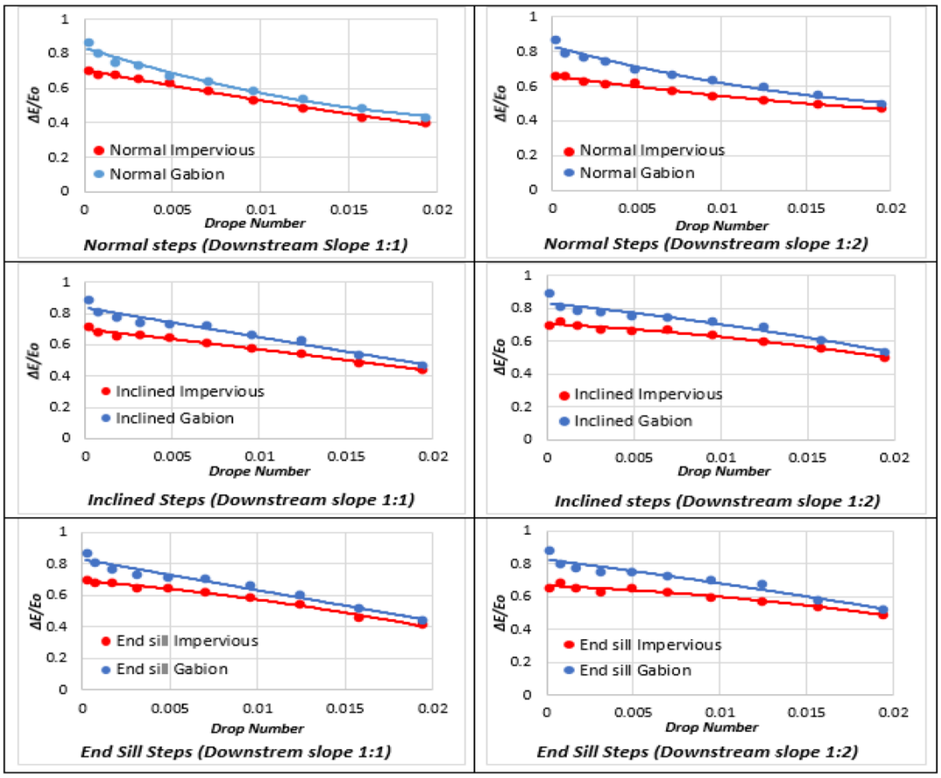

Figure 5. Energy dissipation on gabion and impervious weirs

Figure (6) illustrates the effect of downstream slope on energy dissipation efficiency.

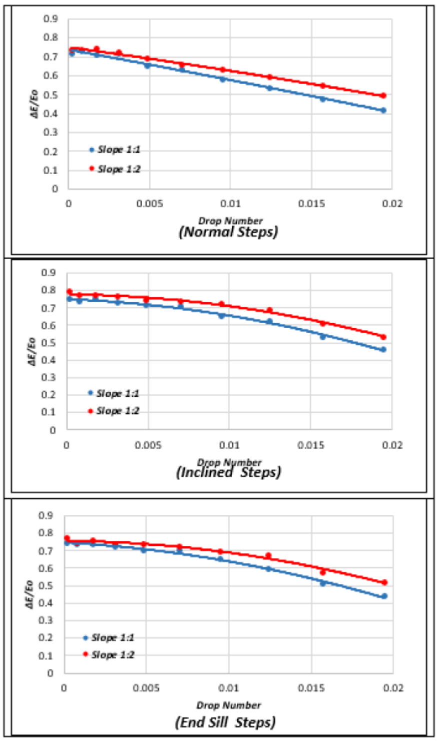

Figure 6. Effect of downstream slope on energy dissipation in gabion weirs

The effect of the slope was the same for all step face configurations. The downstream slope had no effect on energy dissipation at low rate of flow (through-flow). At low discharges (through-flow regime), the downstream slope had no effect on energy dissipation, and the two slopes had the same efficiency, but the downstream slope effect appeared when the overflow regime started.

The energy dissipation increased as the downstream slope decreases for all step face geometries. The energy dissipation increased by 8% when the downstream slope decreased from 1:1 to 1:2. This due perhaps to the greater contact surface in a 1:2 slope than a 1:1 slope. This results have good agreement with previous studies such as Salmasi, Chamani [1], Peyras, Royet [3]. However, Kells [4] stated that the downstream slope has no clear effect on energy dissipation.

5. Conclusions

1. Energy dissipation efficiency decreases with increases in discharge for all downstream slopes and step configurations.
2. Gabion weirs have more energy dissipation than impervious weirs from 17%–20% for low rate of flow (through-flow regime) to 3% for high rate of flow (skimming flow regime).
3. At medium discharge (nappe flow and transition flow regimes), the effect of step face geometry was clear, and inclined steps and end sill steps offered 10% higher energy dissipation than normal steps.
4. Energy dissipation increased with decreases in the downstream slope for all step configurations, and the downstream slope of 1:2 had approximately 8% more energy dissipation than 1:1.

References

[1] SALMASI, F.; CHAMANI, M. R.; ZADEH, D. Farsadi. Experimental study of energy dissipation over stepped gabion spillways with low heights. Iranian Journal of Science and Technology. Transactions of Civil Engineering, 2012, 36.C2: 253.

[2] STEPHENSON, D. Gabion energy dissipators. In: Proc. 13th ICOLD Congress. 1979. p. 33-43.

[3] PEYRAS, Let al; ROYET, P.; DEGOUTTE, G. Flow and energy dissipation over stepped gabion weirs. Journal of Hydraulic Engineering, 1992, 118.5: 707-717.

[4] KELLS, J. A. Energy dissipation at a gabion weir with throughflow and overflow. In: Ann. Conference Can. Soc. Civ. Engrg., Winnipeg, Canada, June. 1994. p. 1-4.

[5] CHINNARASRI, Chaiyuth; DONJADEE, Somchai; ISRANGKURA, Udomsak. Hydraulic characteristics of gabion-stepped weirs. Journal of Hydraulic Engineering, 2008, 134.8: 1147-1152.

[6] WÜTHRICH, Davide; CHANSON, Hubert. Hydraulics, air entrainment, and energy dissipation on a Gabion stepped weir. Journal of Hydraulic Engineering, 2014, 140.9: 04014046.

[7] CHANSON, Hubert (ed.). Energy dissipation in hydraulic structures. CRC Press, 2015.

[8] TE CHOW, Ven. Open channel hydraulics. McGraw-Hill Book Company, Inc; New York, 1959.

[9] DIEZ-CASCON, J., et al. Studies on the hydraulic behaviour of stepped spillways. International water power & dam construction, 1991, 43.9: 22-26.

[10] MATOS, Jorge; QUINTELA, António. Discussion of “Jet Flow on Stepped Spillways” by Jorge Matos and António Quintela. Journal of hydraulic engineering, 1995, 121.5: 443-444.

[11] PEGRAM, Geoffrey GS; OFFICER, Andrew K.; MOTTRAM, Samuel R. Hydraulics of skimming flow on modeled stepped spillways. Journal of hydraulic engineering, 1999, 125.5: 500-510.

[12] ANDRÉ, Stéphanie; SCHLEISS, Anton. High velocity aerated flows on stepped chutes with macro-roughness elements. EPFL-LCH, 2004.