Characteristics of scour down stream of Buttress Gabion spillways

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Abstract

Gabions structures are used to decrease the effect of potential energy existed at the low-heading up structures to protect these structures from collapse because of scour. Buttress gabion spillways are a potential option as a modification of classical gabions for being more suitable for medium and high heading up structures. This study aims to investigate the effect of using Buttress gabion spillways with two stiffeners in the longitudinal-direction of the gabion on the hydraulic performance and their impact on scour downstream of the basin. For this purpose, three experimental buttress gabion models with different stiffeners' widths (i.e. 18mm, 22.5 mm, 32.5 mm) were tested. The height of these models is 20 cm with 5 steps; each step has a 7cm horizontal projection and 4 cm vertical projection. The models were made of stainless steel covered with narrow steel mesh. While the stiffeners were made of coated wooden against water. A classical gabion model with particle size diameter (5 mm) and a solid model were tested to compare the results with the buttress gabion spillways. From results, it's elucidated that the energy dissipation decreases as the relative buttress width ratio increases. On the other hand, the relative sequent depth of the jump and the maximum scour depth increase as this ratio increases. Therefore, the results of this study may be recommended in the field of applications.

Key words: Gabion spillway, Buttress, Energy dissipation, scour.

1-INTRODUCTION

Gabion spillways are widely used at low-heading up structures. The traditional gabion spillways has a small resistance against shear stress due to the movement of flowing water. Therefore, a novel type of gabions called 'buttress gabion spillways' was introduced by some researchers to enhance the resistance of these structures against shear stress by using stiffeners, which are uniformly distributed along the transversal direction. The presence of these stiffeners makes gabions more suitable for medium and high heading-up structures.

Many researchers have studied the heading-up structures because of its importance. All of these studies aimed to get the most economical and efficient option upon energy dissipation and scour.

In order to investigate the effect of different parameters on scour downstream of a free overfall spillway, Ghodsian et al. [1] conducted extensive experiments. From this study, it's found that the scour parameters are a function of downstream Froude number, relative total head and relative sediment mean size. They also obtained accurate dimensionless equations for the prediction of scour parameters. Shafaei-Bajestan and kazemi [2] experimentally found that the scour hole dimensions in simple stepped spillway is larger than the pooled stepped spillway. Chatila and Jurdi [3] examined ogee-profile stepped spillways viability as an alternative to smooth-back spillways. It was found that the number of steps is the main effective factor in expending flow kinetic energy and, therefore, reducing the length of the downstream forming hydraulic jump. Tabbara et al. [4] numerically simulated the water flow over stepped spillways with different step configurations using Adina software. The main characteristics of the flow were investigated for all cases. The predicted water surface profile over the entire length of the spillway was in good agreement with the experimental measurements. The predicted energy dissipation was also compared to the experimentally attained values. Gonzalez et al. [5] studied smooth and rough stepped spillway and three types of step roughness. The results concluded that smooth (concrete) stepped spillway needs different design guidelines than the rough stepped chutes. Hunt and Kadavy [6] investigated physically the effect of steps height on energy dissipation. A two-dimensional model was constructed to evaluate the energy dissipation on a 4(h):1(v) slope spillway chute. It was found that the increasing of step height increases the energy losses at similar locations within the spillway chute. Felder and Chanson [7] studied physically the effect of non-uniform steps on flow patterns, energy dissipation and flow resistance. Five stepped configurations were tested for $0.7 < Dc/H < 1.9$ (Where Dc is the critical water depth and H is the spillway height). The basic findings showed that there are minor differences between all configurations and indicated that the rate of energy dissipation was nearly the same for the uniform and non-uniform stepped configuration. Zhang and Chanson [8] investigated the air entrainment process in the stepped cavity of a gabion stepped spillway through physical modelling. The measurements showed relatively lower aeration, velocity and turbulence levels than that in the mainstream flow. Davideh and Shafaei-Bajestan [9] studied the flood disposal systems and energy dissipation in the construction of Shahid Abbas pour Dam which built to prevent flood damage and water depletion in excess of the capacity of dam reservoir. Twenty equations were provided to determine Scour depth of the spillway coastal martyr of Shahid Abbas pour Dam was modelled by Mike software. These equations are highly compatible the standing scour according to local circumstances and information available from the district. Habib et al. [10] conducted experimental study on the scour geometry downstream a sloped spillway and a spillway with different steps (i.e. 2, 3, 4, 5, 7 and 8). It was found that the spillway with steps over performs the sloped spillway, and the spillway with three steps gives the smallest value of scour depth. Good agreement prediction equations were developed using the multiple linear regression (MLR) to model the relative scour depth Ds/yup versus the relative energy loss $\Delta E/Eup$. Vashisth [11] studied the effect of energy losses using different parameters like velocity of flow, discharge characteristics, depth of flow and energy losses over the stepped gabion type weir and the results showed that the effect of various parameters played significant role for dissipation of energy to avoid the excessive erosion action phenomenon .While, the experimental study of Elnikhely [12] investigated the effect of using cylinder blocks fixed on the back slope of the spillway on the scour hole dimensions downstream of the spillway under different flow conditions. From this study, a simple formulae was predicted to estimate the different scour parameters. Aal et al. [13] studied the gabion and buttress gabion spillway and found that the using of large particles increase the energy dissipation and the coefficient of discharge. Also, as the number of buttress walls increases, the energy dissipation and the coefficient of discharge decrease.

From the previous survey the studies in the field of gabion and buttress gabion spillways are few, whether in energy dissipation or scour, so this study tends to focus on buttress gabion in the field of energy dissipation and scour.

2-DIMENSIONAL ANALYSIS

The dimensional analysis based on Buckingham theory was used to develop a functional relationship between the maximum depth of the scour hole and the other variables as presented in Eq. 1. The maximum depth of the scour hole (Ds) downstream of the buttress gabion spillways can be defined as follows:

$$\frac{D_s}{Y_{up}} = f(F_{up}, \frac{y_2}{Y_{up}}, \frac{\Delta E}{E_{up}}, \frac{D}{H_s}, \frac{B_s}{B})$$

Eq. (1)

As shown in figure 1, B is the width of the canal, Bs is the sum of the buttress width, D is the particle diameter, Ds is the maximum depth of the scour hole, g is the gravitational acceleration, Hs is the dam height, Y1 is the initial water depth, Y2 is the sequent depth of hydraulic jump, Yup is the upstream water depth, ΔE is the energy loss between the upstream and the downstream at the end of the hydraulic jump and EUP is the energy upstream of the gabion.

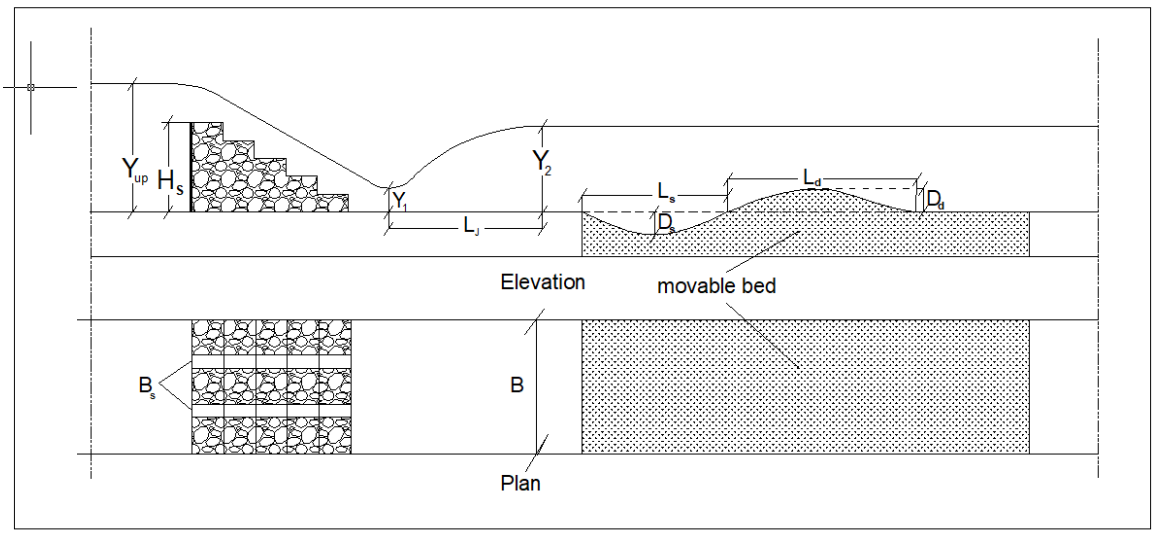

Figure (1) Definition sketch of experimental model.

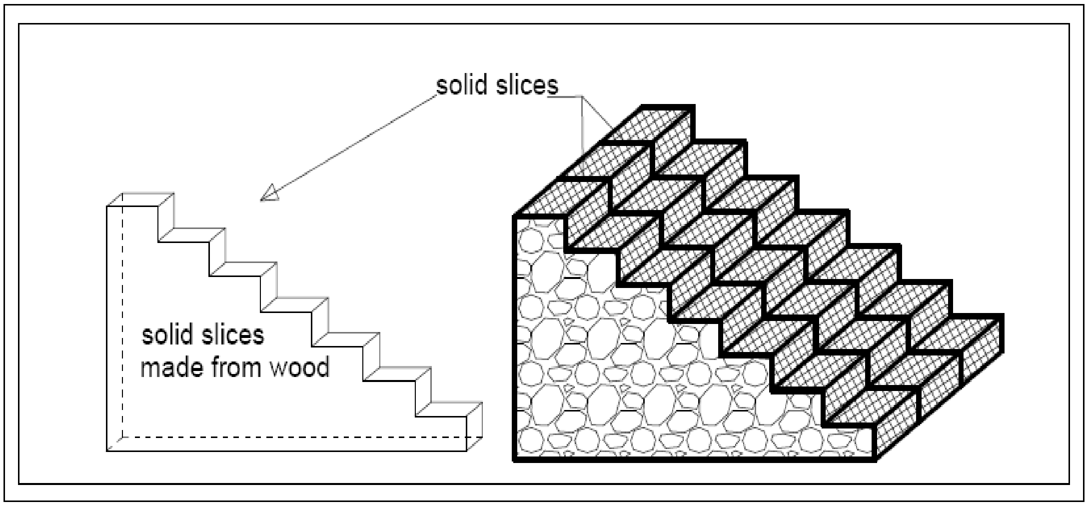

Figure (2) Sketches of Buttress Gabion Model.

3-EXPERIMENTAL WORK

The experimental work was performed in the Hydraulic Engineering Laboratory of the Faculty of Engineering, Zagazig University, in Egypt. The used flume is 29.8 cm in width, 45.6 cm in depth and an overall length of about 15.6 m. The end tailgate of the flume is used to control the tail water depth. The flume is equipped with a pump which is used to circulate the water from the tank to the flume inlet. While a pre-calibrated orifice meter installed in the feeding pipe line is used to measure the passing discharge.

The used buttress gabion spillway model was made of stainless steel covered with narrow steel mesh. The height of model is 20 cm with 5 steps; each step has a 7cm horizontal projection and 4 cm vertical projection. The upstream wall is supported by two stiffeners of coated wood against water.

In the flow direction along the body of the gabion buttress spillway model, two equal thickness “1.8, 2.25 and 3.25 cm” stiffeners were studied. As shown in Figure.3, three buttress gabion models are used to investigate the under study phenomena. The gabion models were filled with particle size diameter (5mm). The model set on a solid base with length of 40 cm followed by a sandy soil to simulate the scour. The sand sample was tested using sieve analysis to find the percentage of each particle size as shown in figure (4). The data analysis showed that the median particle diameter of sand (d_{50}) equals 0.5 mm. The flowing discharge in the flume ranged from 9.5 to 22 lit/s.

About 35 runs were tested with different flow rates for all models. After placing the desired gabion model, the required flow discharge was adjusted by the inflow valve and the tailgate to form the hydraulic jump just downstream the model.

Figure (3) The experimental gabion stepped spillway model

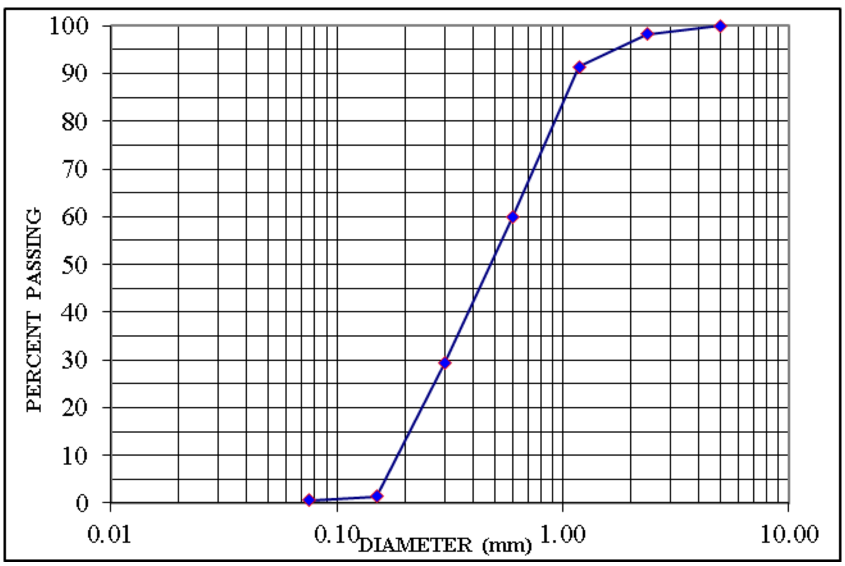

Figure (4) sieve analysis chart

4- ANALYSIS AND DISCUSSION

The hydraulic performance (i.e. ($\Delta E/E_{up}$), Y_2/Y_{up} , and D_s/Y_{up}) of different three models namely: classical gabion spillway, solid spillway, and buttress gabion spillway is investigated under different values of Froude number. In classical gabion spillway, there is no stiffeners whereby the relative buttress ratio (B_S/B) takes a value of zero. With the existence of stiffeners in buttress gabion spillway, this ratio takes a value between zero and unity, based on the width of the stiffener. While it takes a value of unity in solid spillway.

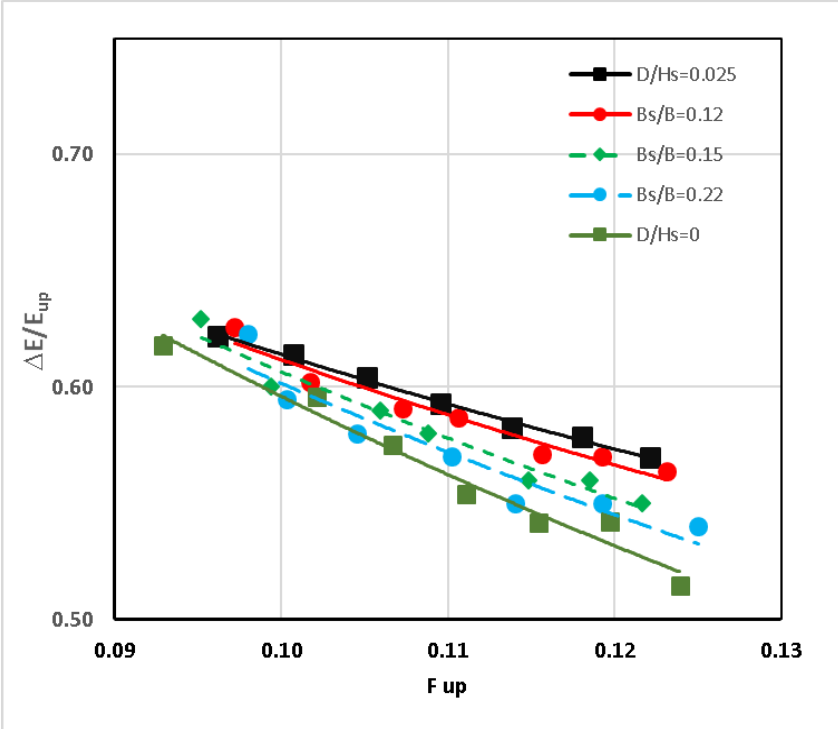

Figure (5) Relations between F_{up} and $\Delta E/E_{up}$.

Figure.5 shows the relationship between the upstream Froude number (F_{up}) and the relative energy loss ($\Delta E/E_{up}$). From this figure, as the upstream Froude number increases, the relative energy loss decreases for all models. It is elucidated that the classical gabion model gives the maximum value of relative energy loss at the same value of Froude number. Whereas it reaches the minimum value in the case of the solid spillway. For buttress gabion spillway, the value of relative energy loss decreases with the increase of the relative buttress ratios.

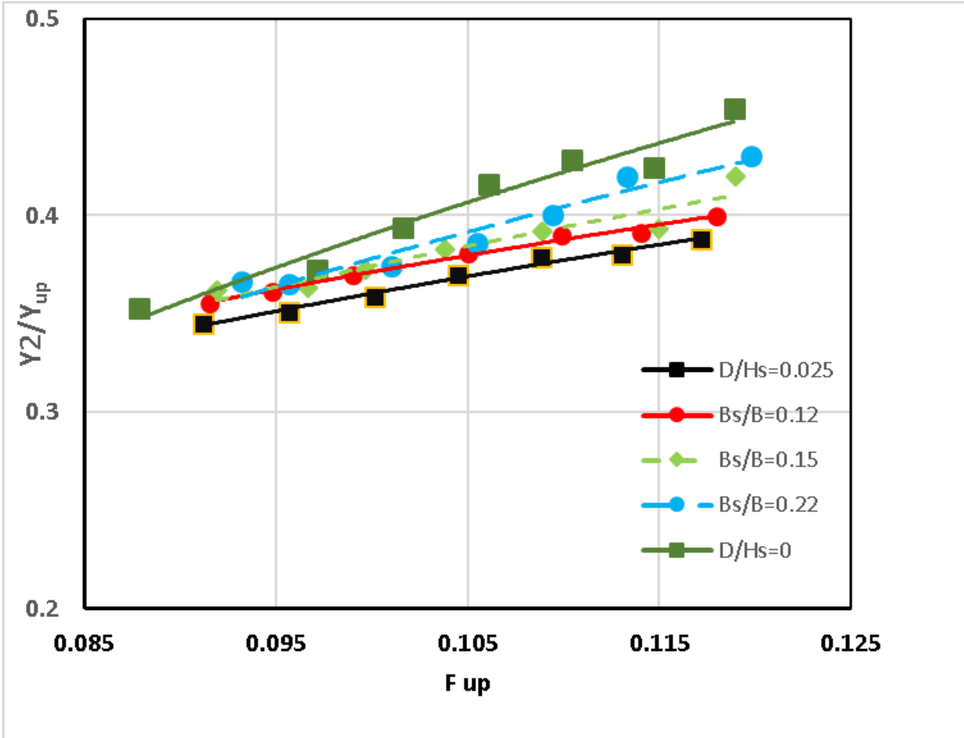

Figure (6) Relations between F_{up} and Y_2/Y_{up} for different buttress relative ratio.

Figure.6 presents the growing linear relationship between the upstream Froude number (F_{up}) and the relative depth of the hydraulic jump (Y_2 / Y_{up}). The case of classical gabion spillway gives the minimum values of relative depth while the solid spillway gives the largest values of the relative depths of jump. All values of the relative depths of jump for buttress spillway lay between the above two cases. As the buttress relative width increases, the relative depth of jump also increases.

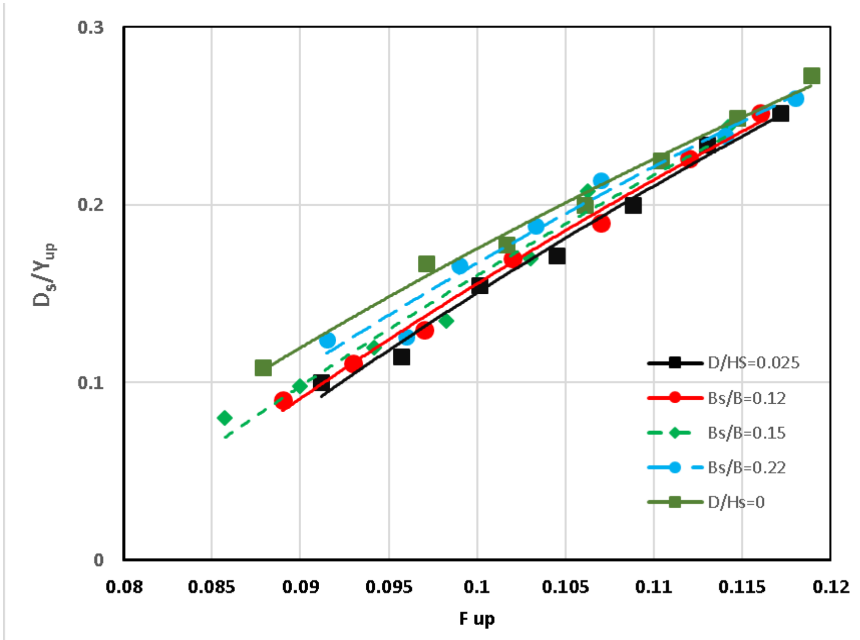

Figure (7) Relations between F_{up} and D_s/Y_{up} for different buttress relative ratio.

From this figure, there is a linear positive relationship between the relative scour depth and the upstream Froude number. All Buttress gabion spillways give scour depth values more than the classical gabion and less than the solid spillway. The effect of buttress on the maximum scour depth is clearly observed at lower upstream Froude number. However, at higher values of upstream Froude number, there is no a noticeable difference between the different models. The porosity of soil gabion plays an important role in scour phenomena whereby a part of flow passes through the soil voids towards the toe of gabion spillway. This flow mixes with the flow coming over the gabion spillway. Hence, the velocity behind the structure is slowed down; and consequently, a part of kinetic energy transforms to a potential energy and the scour mechanism is decreased. The buttress represents an obstruction to water from passing through gabion soil. For no buttress (B_s/B) =0, the expected flow rate through gabion soil is more than all cases associated to the buttress gabion spillway. This elucidates why all buttress ratios give larger scour depths more than the classical gabion spillway at the same flow conditions. Moreover, at the same Froude number the solid spillway gives the largest relative scour depths compared to other tested models of buttress and classical gabion spillway. The ability of soil to pass water through it is ended at a certain limit. This limit depends on soil properties and the upstream water depth.

A strong relationship is observed among the relative energy loss, the relative depth of jump and the relative maximum scour depth. To illustrate this, as the relative energy loss increases, the relative depth of jump and the relative maximum scour depth decrease. However, when it decreases, the major part of kinetic energy is converted to a potential energy; hence, water flow velocity is decreased and the scour mechanism process is also reduced which in turn the scour depths are decreased.

5- CONCLUSIONS

From the results of the present study, the following conclusions can be introduced.

1- When the relative buttress wall width ratio increases the energy dissipation decreases.

2- The relative depth of the hydraulic jump and the relative scour depth increase by increasing the relative buttress wall width ratio.

Notation

B	The width of the canal
B_S	The sum of the buttress width
D	The particle diameter
D_s	The maximum depth of the scour hole
g	The gravitational acceleration
H_s	The spillway height
Y_1	The initial water depth
Y_2	The sequent depth of hydraulic jump
Y_{up}	The upstream water depth
ΔE	The energy loss between the upstream and the downstream at the end of the hydraulic jump
E_{up}	The energy upstream of the gabion spillway

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