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Effect of Perforated Inclination and Height of Sill on Maximum Scour Depth and Energy Losses Downstream a Sluice Gate

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ABSTRACT

Screens have proven to be an effective choice for decreasing scour downstream of small hydraulic structures. This paper studies experimentally the performance of an inclined perforated sill with a fixed porosity of 41.1% and varied height. Six different relative heights (from 0.34 to 2.25) and inclination angles of screens (30 °, 60 °, 90 °, 120 °, and 150) were tested under different flow conditions. The presence of a screen in the stilling basin reduced the maximum scour depth until the relative screen height was less than two compared to the no-screen case. A relative screen height greater than two increases the maximum scour depth. The best relative height of the screen is found to be approximately unity from the scour point of view. while the relative energy loss increases positively with the relative screen heights. Moreover, the vertical angles provide the best conditions for scour and energy dissipation. Finally, an empirical equation was developed to predict the maximum scour depth. A good agreement was found between the results of the predicted equation and the experimental results, with a mean relative error of about 6%.

1. Introduction

The generation of water energy as a result of high-water flow velocity downstream hydraulic structures exit. The goal of the water resources engineers is to release the energy without endangering the hydraulic structure. Engineers have, therefore, made considerable efforts to protect the hydraulic structures' downstream from scouring and local scour as well as the components of the hydraulic structures from damage. Fundamentally, five types of energy dissipation methods are introduced, including roller buckets, stilling basins, free jets, and hydraulic jumps**. chow, 1959** [**1**]. The difficulties associated with impact energy dissipation (the screen is classified under this group) must dissipate the kinetic water energy within a short distance of the water flow domain (i.e., return the flow condition to normal). This feature is a practical need as it reduces the cost of hydraulic structure construction. As a result, using porous screens (or porous baffles) as energy dissipators is a viable alternative to traditional hydraulic jump dissipation structures. In this regard, Karrh [**2**] made the first experimental effort to investigate the performance of a perforated screen wall. Similarly, **Krishnakumar et al.** [**3**] conducted significant experimental work when the screens produced partially or completely submerged water waves. The effect of single- and double-wall screens with porosities of 9.1% and 23.1% on head loss was examined. The results showed that the double screen outperformed the single wall screen in terms of energy dissipation. The effective performance of 40% porosity in energy dissipation has been demonstrated

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experimentally with single and double screen walls matching various hole shape geometries [**4**]–[**6**]. As a result, this percentage of porosity is used in this study. The influence of screen wall position downstream of hydraulic structure (sluice gate in several experimental works) was explored. The studies effectively demonstrated that increasing the Froude number increases energy dissipation and that there was a relative relationship between opening the sluice gate and the position of screen walls in a laboratory flume. It had a direct impact on screen performance [**7**]. As a result, this concept is regarded as being validated in this work. The experimental examination of tilted screen performance is still incomplete. **Abdel Haleem** [**6**] employed semicircular baffle blocks to reduce scour downstream of a weir. **Abdel Haleem** examined various block configurations and discovered that all suggested baffle block designs limited the maximum scour depth. Nevertheless, the layout with L_b/L_f = 0.4 and H_b/D_o = 1.33, where L_b, L_f, H_b, and D_o are the distances between the baffle line and the weir's toe, floor length, baffle height, and outer baffle diameter, respectively, provides the greatest reduction in scour length, ranging from 77.06% to 93.66%. **Mesbahi et al.** [**8**] used gene-expression programming to forecast local scour depth downstream of stilling basins, and the Froude number was shown to be the most relevant parameter in predicting maximum scour depth. The results of an experiment conducted by **Farhoudi and Shayan** [**9**] on the local scour downstream of unfavorable stilling basins revealed that scour profiles at any bed incline pursue shape similitude. Also, the greatest depth of the scour hole decreased as the length and slope of the stilling basin increased, despite the fact that the longitudinal dimensions of the hole increased. **Ibrahim** [**10**] investigated the effect of oriented vanes on bed material design in a level stilling basin, aiming to minimize local scour and silting geometry**.** The proposed shape in this exploration is simple to apply as an additional component to the stilling basin of any existing water structures. Two hundred and sixty runs were carried out using ten models of stilling basins with variable vanes' heights and angles under various flow circumstances, including discharges and tailgate water depths. To simulate the impact of vanes installation, a level floor without vanes was included in the test program. The experimental results took into account two distinct bed materials. The findings were examined and visually presented. Straightforward methods for estimating the geometry of local scour and silting were provided. The effectiveness of perforated screens as energy dissipators in mixed triple-wall mode for small hydraulic structures was tested in the lab. When the study's findings are contrasted with those of the prior researchers, it is found that there was more energy lost during the investigation. According to the current study, the proportionate energy loss ranged from 74 to 94%. The Froude number, F2, which is situated downstream of the screen, had an average value that varied from 1.1 to 1.81. If D, the tailwater deficit parameter, is found to fall within the range of 0.66–0.90 [**11**]. In order to reduce the energy of supercritical flow with Froude numbers (F1) ranging from 3 to 19, **Singh and Roy**[**12**] used screens in single and double wall mode with triangular-shaped openings and a porosity of 45% per unit depth. They found that triangular-shaped openings are also just as effective as screens with circular and square-shaped openings. The effectiveness of perforated screens as energy dissipators in mixed triple-wall mode for small hydraulic structures was tested in a lab. **Abbaspour et al.'s** experimental study utilised screens with square holes and a porosity of 50% [**13**]. Screens with an adverse slope of 0.025 dissipated more energy than those with an adverse slope of 0.015. Screens with a double layout performed better and consumed more energy than those with a single configuration. **Elaswad et al.** [**14**] examined the importance of screens for dissipating energy from the submerged hydraulic jump in a suddenly extended stilling basin.. Their findings showed that the ideal screen placement had a relative screen area of 0.285 at 0.25 abutment lengths, which resulted in the greatest energy loss at the lowest tailwater depth and submerged hydraulic jump length. Usually, a hydraulic jump is created and maintained downstream of the hydraulic structures, and the departure velocity is reduced using stilling basins. and discharge the additional energy caused by the supercritical flow [**1**]. In addition to these drops and hydraulic jump-type energy dissipators, [**15**]–[**18**] Jumps are also impact-type energy dissipators. Recently, screens have been considered as a possible replacement for supercritical fly energy dissipation in hydraulically compact buildings. The main objective of this research is to investigate the impact of utilizing a perforated sill (with varying heights and slope angles) on the maximum scour depth and energy dissipation in the presence of a mobile bed using experimental data and the construction of theoretical equations.

2. Experimental Study

2.1. Experimental Flume

The studies were carried out at water and hydraulics engineering laboratory faculty of engineering Zagazig University's in Egypt. A re-circulating flume 15.6 m long, 0.3 m wide, and 0.468 m deep was used in this study (see Fig. 1). The flume bed is built of stainless steel, giving it a high level of stability and rigidity, and the sides are made of glass. Water is recirculated by a centrifugal pump situated at the flume's bottom. Pump capacity up to 25 litres per second, and the discharge measured by an orifice fitted on the delivery pipe of a centrifugal pump. A manually adjusted butterfly valve controls the water flow in the flume. A point gauge with a scale reading of (0.001) m is used to precisely measure the depth of the water level in a flume as shown in fig. 2. Throughout the process, the gate opening (4, 5, and 6 cm) remains constant.

Fig. (1). Laboratory Flume

Fig. (2). A point gauge

2.2. Perforated Sill Models

The material used for the perforated sills is clear Perspex, which is chosen for its easy handling properties, then placed at a distance of 10 cm from the gate in a sudden expanding stilling basin with a constant expansion ratio (e=1.35) downstream the vertical gate[**19**]. They are built of translucent Plexiglas panels with a width of 22 cm and a fixed porosity of 41.1.% [**20**], the screens were located at 10 cm from the gate as shown in Fig. 3. Six different heights of screens were tested with different sluice gate openings, as shown. Also, five inclination angles of screens were tested (30°, 60°, 90°, 120°, and 150°). Fig. 3 clarifies the inclined screen model. Figure 4 shows a definition sketch of the experimental model (discharges, gate openings, screen heights, and orientation angles).

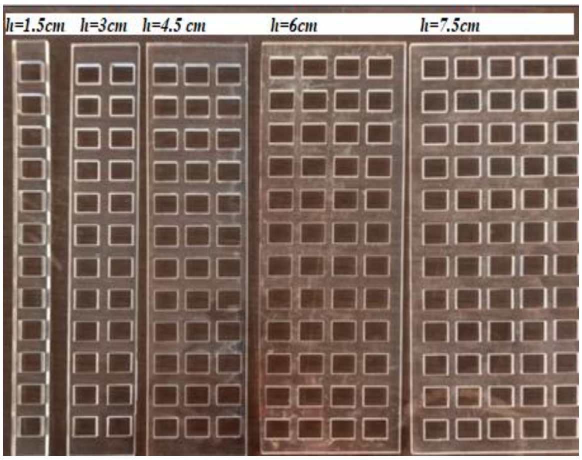

Fig. (3). Perforated sill models

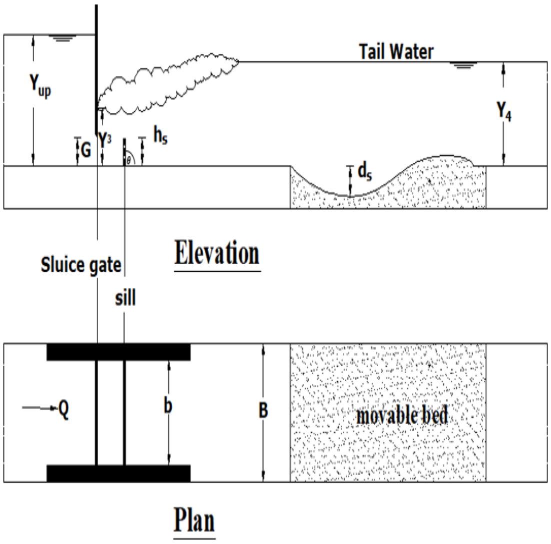

Fig. (4). Definition sketch of the experimental model

2.3. Bed Material

A mechanical sieve analysis test was performed on the bed material used in this investigation. To replicate the mobile bed, the bed material used fine sand with a grain median size of d_{50} = 0.41 mm and a standard deviation of $\delta g = 2.38$, as shown in figure (5)

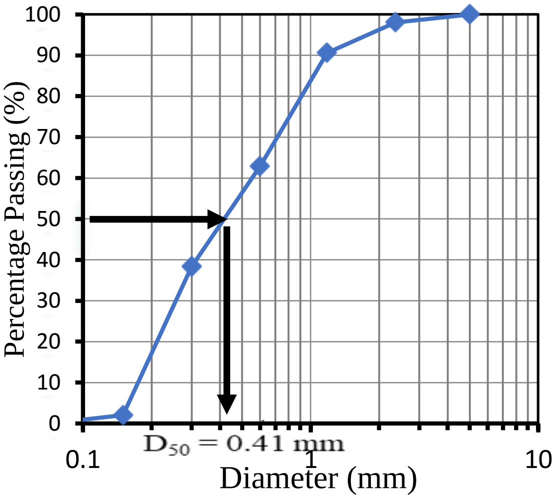

Fig. (5). Sieve analysis of the bed soil sample.

2.4. Experimental Procedure

The flow discharge, hydraulic leap length, and water depths were measured for every experiment. The discharge flow had a constant submergence ratio of (S = 2) and varied between 10 and 16 liter/second. Nine runs for a sluice gate with a submerged hydraulic jump—that is, a case without a sill—were included in the approximately ninety runs that were carried out for comparison. To examine the impact of a sill with varying relative porosity on the maximum scour depth downstream of a sluice gate, the absence of a sill was taken into consideration as the base case. Following the construction of each experiment, the flume channel was filled with bed material (sand) and precisely levelled, and a point gauge was used to measure the levelling accuracy. For each experiment, the following steps were taken.:

1. Close the tail gate and begin backwater feeding the flume until it reaches the necessary tail water depth.
2. The pump's control valve was gradually opened until the necessary discharge entered the flume.
3. An orifice meter mounted on the flume pipe was used to measure the discharge.
4. Using the point gauge, the tail gate was gradually screwed until the necessary downstream water depth was reached.
5. The pump was switched off after two hours, during which the bed profile remained unchanged.
6. Using a point gauge, the lengths and depths of the scour were measured after the flume and scour hole were gradually drained from the water.

3. Dimensional Analysis

Several pilot studies were conducted in order to determine how the perforated sill affected the maximum scour depth downstream of a sluice gate. Many of the flow parameters were characterized in order to do the dimensional analysis, as illustrated in fig. (4), based on the theoretical realization of the flow field between the sluice gate and the perforated sill.

$$f\,(A_{hole}, A_{sill}, B, b, d_{sc}, \mathrm{E}_3, E_4, \Delta E, G, g, V_G, \mathrm{y}_3, y_4, \rho, H_{sc}, \theta) = 0 \qquad \textbf{(1)}$$

where y_1 is the water depth at the beginning of the leap, y_3 is the backup water depth downstream of the jump, y4 is the water depth at the end of the submerged jump, L_j is the jump length, B is the width of the channel, b is the contracted width, and G is the gate opening. , ΔE is the energy lost by the jump, g is the gravitational acceleration, E_3 is the total energy immediately after the gate, and E_4 is the total energy at y_4. ρ represents the mass density of water, while μ denotes its dynamic viscosity. D_{SC} is the maximum scour hole depth, A_{sill} is the entire area of the perforated sill, A_{hole} is the area for holes on the perforated sill, and θ is the sill angle of inclination, H_{sc} is the screen height, and V_1 is the velocity at Venna contract. Using (G, g, and ρ) as a repeated variable and the Buckingham π-theorem, the overall form of the relationship between these variables can be expressed as follows:

$$\frac{\Delta E}{E_G}, \frac{d_s}{G} = f\,\left(F_1, \frac{H_{sc}}{G}, \theta\right) \qquad \textbf{(2)}$$

Since the expansion ratio, median sediment diameter, and relative area of holes (sill porosity) were constants throughout this investigation (EG- E4)/ EG=ΔE/EG represents the relative energy loss through the hydraulic leap. Conversely, the relative screen height is Hsc/G.

4. Analysis And Discussion

Investigations were conducted into the effects of sill heights and positive and negative inclination angles with the vertical line on energy dissipation and maximum scour depth downstream of abruptly increasing stilling basin.

4.1. Sill's height Effect

4.1.1. Vertical sill's height effect on the maximum scour depth

The associations between the gate Froude number and the relative maximum scour depth for various relative sill heights (H/G) are depicted in Figure 6. For various relative sill heights (H/G). Figure 7 illustrates the relationship between ds/G and H/G at Gate Froude number FG = 2. Figure 6 shows that the maximum scour depth grows in tandem with the gate Froude number. Additionally, at a certain Froude number (FG = 2), for instance, the relative screen height grows and the maximum scour depth falls until the relative screen height approaches unity (H/G = 1.0), at which point the relative scour depth hits its minimal values. Furthermore, when the relative screen height rises above unity and the scour processes become more intense, the relative scour depth rises once more. While it starts to rise, the maximum scour depth is still lower than in the analogous scenario without a screen. Figure 7 illustrates that the maximum scour depth in this scenario is above the no-screen situation when the screen relative height is more than about two.

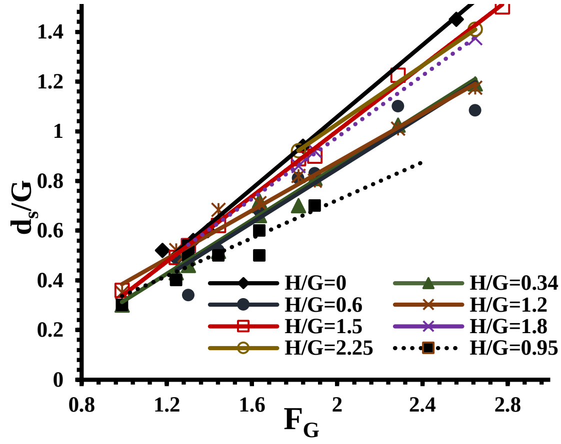

Fig. (6). Relation between the relative maximum scour depth **d_s/G** and Gate Froude number **F_G** for different heights.

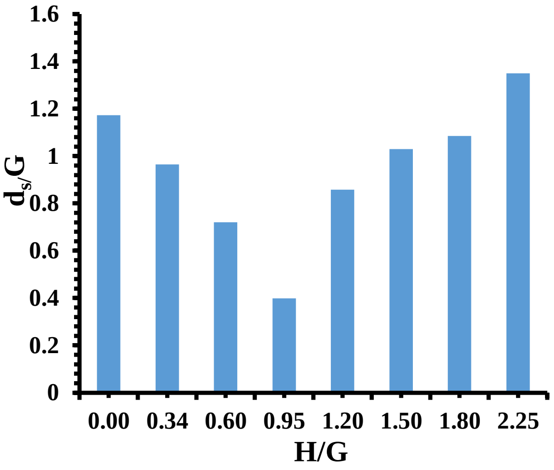

Fig. (7). Relation between d_s/G and H/G for **Gate Froude number F_G** =2

4.1.2. Vertical sill's height effect on the Relative energy losses (ΔE/E1)

The relationship between the gate Froude number (FG) and the relative energy losses (ΔE/EG) for various relative sill heights (H/G) is shown in Figure 8. The relationship between ΔE/EG and H/G with Gate Froude number FG = 2 is depicted in Figure 9 for various relative sill heights (H/G). Figure 8 shows that for all relative heights of screens, the relative energy losses (ΔE/EG) rise linearly with increasing gate Froude numbers. Additionally, as figure 9 illustrates, given a constant Froude number, the relative energy lost rises positively as the screen's relative height grows. Actually, a portion of the current flow goes through the opening in the screen, while the remaining portion goes over the screen. Logically, the subsurface velocity increases as the discharge passes through the apertures. Consequently, the scour mechanism gets stronger. Additionally, the jet of flow crosses the screen shocks as the screen height rises. The scour depth increases when the passing flow approaches the moveable bed. There was not much of a barrier in the bed due to the little screen's relative height. The scour process steadily diminishes up to a predetermined screen height (unity). Additionally, the scour process is becoming worse, increasing, and losing its small relative screen height competitive edge. Furthermore, as the screen's relative height rises, so does the influence between the current flow and the screen body. Thus, the relative energy loss rises as more eddies and turbulence arise.

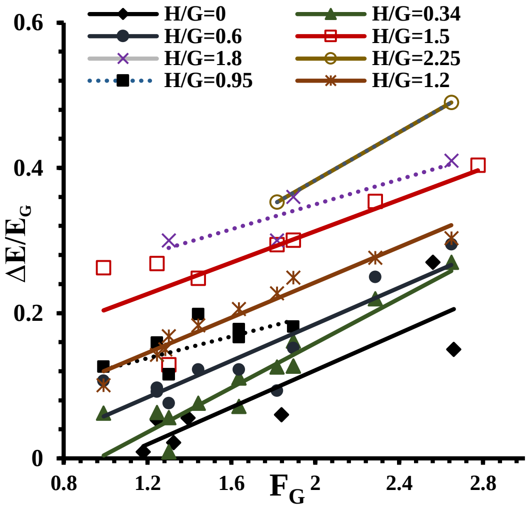

Fig. (8). Relation between the Relative energy losses $\Delta E/E_G$ and the Gate Froude number (F_G) for different sill's heights.

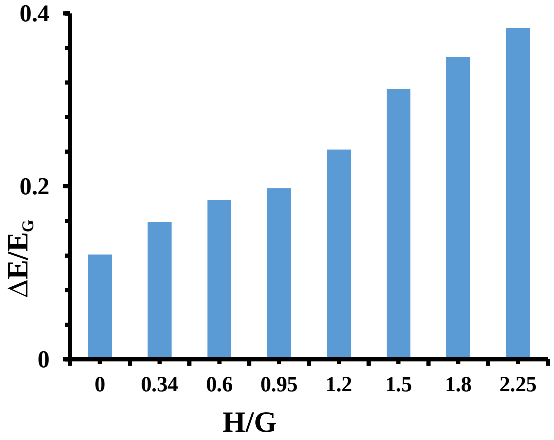

Fig. (9). Relation between ΔE/EG and H/G for Gate Froude number (FG) =2.

4.2. Sill's inclination Effect

The effect of screen inclination angles on the maximum scour depths at relative screen heights of 0.5 and 0.87, respectively, was investigated. Figures 10 and 11 depict the relation between the relative scour depth ds/G and the Gate Froude Number (FG) for H/G =.5 and 0.87, respectively, for various screens' inclination angles. According to these figures, the vertical screen provides the lowest relative scour depth readings throughout all screen inclination angle tests. Actually, two components of the velocity vector for the positive screen inclination angles were examined. The first is the flow that is going up and parallel to the screen, and the second is the flow that is going down and perpendicular to the screen. The subsurface (near bed) velocity increases slightly due to the downward flow, producing more eddies and a more pronounced scour process. Conversely, a stronger backflow and a higher water head were generated upstream of the screen by the negative screen inclination angles. Consequently, there is a greater differential head between the screen's upstream and downstream. When the water jet crosses the forward flow via the screen holes at a distance from the screen, it behaves like a projectile and closes the moveable bed. In light of this, the maximum scour is raised.

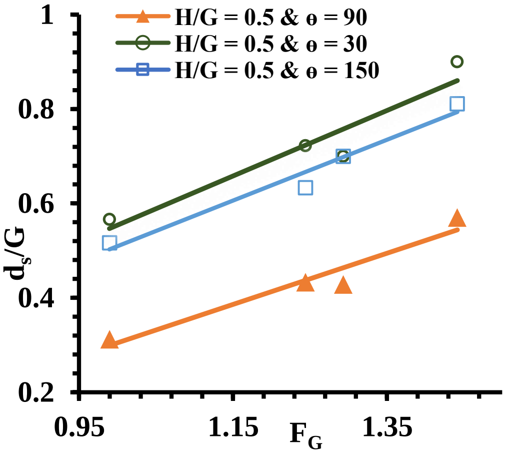

Fig. (10). Relation between the relative scour depth ds/G and the Gate Froude Number (FG) for H/G=.5

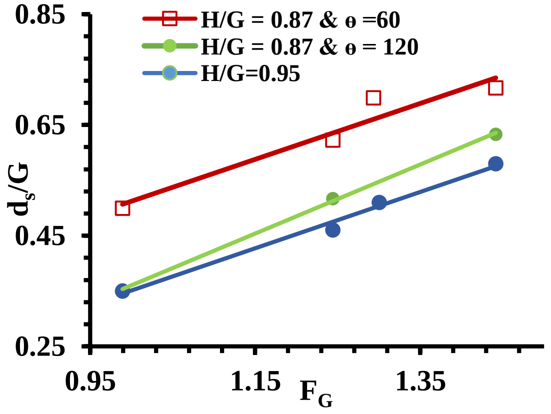

Fig. (11). Relation between the relative scour depth ds/G and the Gate Froude Number (FG) for H/G=.87

4.3. Sill's inclination Effect on the Relative energy losses (ΔE/EG).

The impact of relative screen height (H/G =.5 and.87) on the relative energy loss for various screen angles of inclination is depicted in Figures 12 and 13. These figures show that the vertical angles enhance the energy loss performance. Both the positive and negative inclination angles decreased the relative energy loss; however, the positive inclination angle causes a greater relative energy loss than the negative inclination angle. It is thought that the scour events slow down and the proportional energy loss increases as the angle of inclination approaches the vertical angle

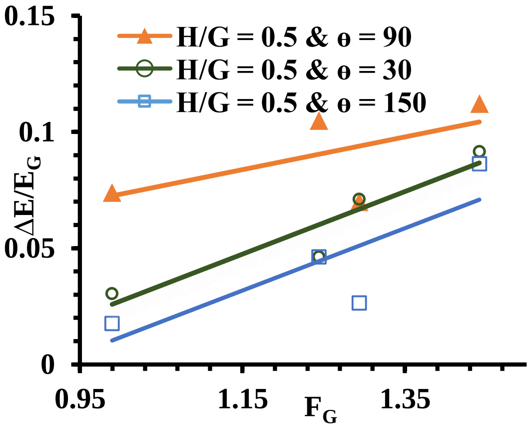

Fig. (12). Relation between the Relative energy losses ΔE/EG and the Gate Froude Number (FG) for different Sill's slopes

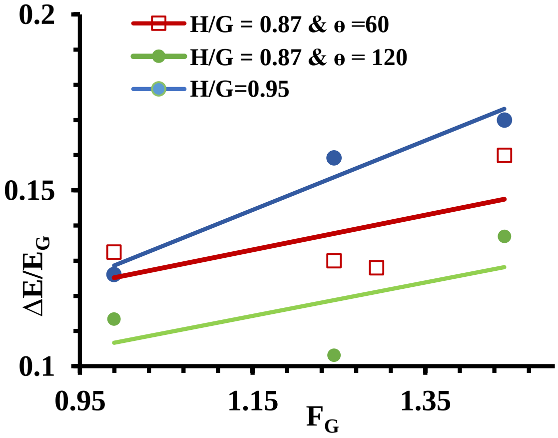

Fig. (13). Relation between the Relative energy losses ΔE/EG and the Gate Froude Number (FG) for different Sill's slopes

5. STATICAL ANALYSIS

Regression analysis was used to create prediction models that connected the relative maximum scour depth to other independent parameters in each of the simulated scenarios. Numerous experiments were conducted in order to obtain a generic equation that represented all of the independent parameters. An approximated equation for predicting the scour depth that occurred was derived from a number of laboratory tests, or around 70% of the total. The remaining trials were used to verify that the predicted equation was accurate. This equation's determination coefficient was extremely tiny, making it unable to convey the relative scour depth. Thus, the following predicted equations were developed for several simulated models:

$$\frac{d_s}{G} = -0.2 + 0.6F + 0.07\frac{H}{G} - 0.156\sin\theta \qquad \textbf{(3)}$$

The determination coefficients = 95%, and stander errors =0.06. Figure 14 shows the relation between Predicted values of Eq. (3) versus measured data for relative scour depth. Figure 15 shows the relation between Residuals and measured (ds/G). It was found that the predicted equations express well agreement to the measured data. Figure 15 shows the random distribution of residuals around the zero line and the poor R^2 of residuals indicates the better relationship of predicted and experimental results.

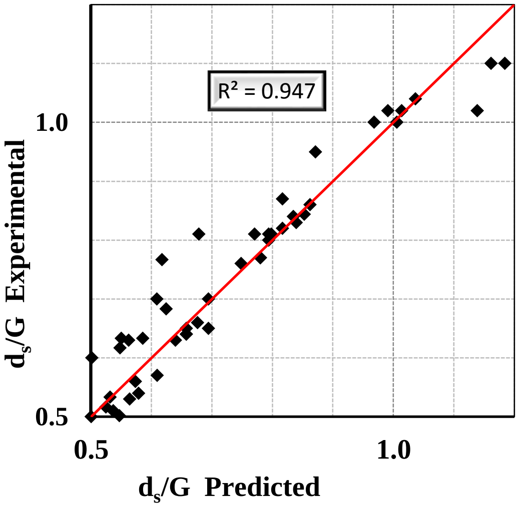

Fig. (14). Comparison between predicted and experimental (ds /G)

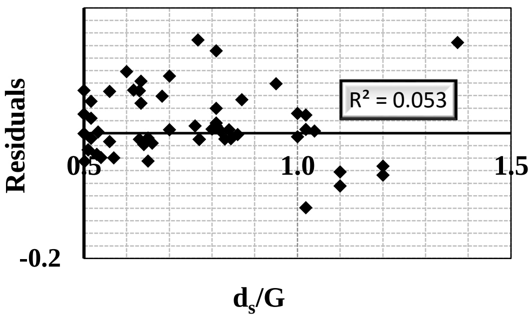

Fig. (15). Comparison between Residuals of equation (3) and experimental (ds/G)

6. CONCLUSIONS

The current study used experiments to examine how the screen's inclination affected its scour and energy dissipation capabilities. Measured in the vertical plane from the channel bed, the screen's inclination angles of 30, 60, 90, 120, and 150 degrees were selected. The following conclusions were drawn after the experimental data was analysed:

1. The maximum scour depth increases with increasing the Froude number for all experiments.
2. The lowest values of the relative scour depth are given by the relative screen height, which is roughly equal to unity.
3. Within the experiment, the relative energy loss rises linearly with the relative screen heights.
4. The vertical angle provides the lowest values of scour depth for all relative screen heights for all tested screen inclination angles.
5. The vertical angle provides the maximum energy loss in the experiment results for all relative heights of the screens.
6. For the relative scour depth prediction, an equation has been developed that fits the measured data accurately.
7. The maximum standard error of 6% will be found in the predicted equation of scour depth matching with the experimental data.
8. In the future, more studies need to be done on the use of perforated sills and their comparison with non-perforated sills.

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