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The Effect of Weight and Position on Energy Dissipation in Multi-pendulum Sill

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Abstract

Energy dissipation downstream of hydraulic structures is one issue that engineers involved in hydraulic irrigation design must consider. This paper describes a new technique for increasing energy dissipation and shortening the floor length of a hydraulic design. The pendulum sills were plastic cylinders of 29.5 cm in length, with diameters of 3.75 and 5.00 cm and wall thickness of 5 mm. The sill's position relative to the hydraulic leap was altered by varying the weight and string length. Each diameter's sill weight was modified to six different values. The results showed that using a pendulum sill increased energy dissipation significantly. It was observed that utilizing the weight 1121kg is the best solution since energy dissipation increases by approximately 55% with increasing string length and number of sills.

1. Introduction

The hydraulic jump is one of the most effective methods for releasing energy in hydraulic systems. The goal of many studies is to improve energy dissipation in order to improve jump performance. **Hager et al.** [1] investigated the initial leap conditions for flow across ventilated continuous sills using a simple, one-dimensional approach. The drag coefficient for gravity free flow was shown to be independent of the relative height of the sill. A relationship between the initial Froude number and the relative height of the sill might be established. Through an experimental investigation of the relative energy losses in sloping channels, **Gupta** [2] establishes an empirical relationship between the initial Froude number and the relative energy losses for different channel bed slopes.**Gupta et al.** [3] developed a formula empirically for the relative energy losses and discovered that the relative energy loss of the free leap increases as the approach Froude number increases. **Bestawy** [4] 14 distinct baffle pier models were employed in the experimental study to dissipate water energy downstream of a heading-up structure. Overall, the results indicate that models with concave surfaces dissipate more energy than other forms and cause the flow to change direction more than those with low turbulence intensity in the recirculation zone downstream of baffle piers. Additionally, the study demonstrates that, when it comes to dissipating water energy, the vertical semi-circular portion has the most impact among the examined models. **Ahmed et al.**[5] Examined experimentally how the properties of submerged hydraulic jumps were impacted by the use of triangular strip corrugations with different spacing. The beds were smooth and corrugated. Studies were done on a range of Froude numbers, from 1.68 to 9.29. The findings showed that using spaced triangular corrugated aprons reduced the hydraulic jump length and subsequent depth ratio by 21.03% and 15.14%, respectively, but enhanced the leap's energy dissipation efficiency by 50.31%. **Kim** [6] conducted studies to examine the differences between each kind of weir and the resulting hydraulic jump using a canal that featured both a fixed weir and a movable weir installation of the sluice gate type. When compared to the installation status of non-dissipaters, it was found that the energy dissipaters for energy reduction at the sluice gate would dissipate energy by more than 50% per unit length if placed at a height of 10% of the average river water depth in a location as far as roughly 70% of the average river water depth. **Eltoukhy** [7] conducted experiments in the lab to examine the hydraulic jump characteristics of different rectangular open channels with different bed slopes. To disperse the leap energy, El Toky develops an equation to calculate the sill height and the proportionate energy losses. **Mansoori et.al.**[8] FLOW-3D was used to evaluate and determine the energy dissipation rate in this numerical study. After reading relevant literature, the suggested model was created in FLOW-3D to establish the optimal geometry of the steps that would allow for the greatest amount of energy dissipation. Analyses were conducted utilizing the aforementioned techniques and trial and error in mesh network sizes in order to assess the suggested approach, and the outcomes were contrasted with those of other studies. Stated otherwise, a Λ-shaped step at a 25-degree angle produced the most ideal condition in terms of energy dissipation rate when compared. **Abdelmonem et. al.**[9] Experimentally, we investigated how using a suspended pendulum sill with a fixed weight affects the energy dissipation of the downstream sluice gates.

Because the pendulum still wastes energy by more than 20%, it was observed that inserting it improves the hydraulic jump's performance. **Urbański** [10] The model of the sluice gate and stilling basin was investigated using two different configurations of baffle blocks: one and two rows. The study found that the two rows of baffle blocks in the stilling basin reduced the length of the hydraulic jump by 5-10% as compared to the single row of blocks**. Abd El Ghany et.al.**[11] An experiment was conducted utilizing a hanging pendulum sill. It was discovered that using a pendulum sill has the advantage of being a fixable technique of energy dissipation because it can be adjusted in position and height. However, after conducting experiments with various sill weights, heights, and locations, it was discovered that staggered blocks with a specified intensity outperformed hung sills.**Tohamy et. al.** [12] used Flow 3D software to simulate the effect of placing a vertical screen downstream hydraulic structure as an energy dissipater device. The study found that utilizing a screen downstream vertical gate is an excellent way to dissipate energy. **El-Saie et. al.**[13] The forced hydraulic jump characteristics were quantitatively investigated using Flow-3D software. Rectangular and semi-cylindrical slices were utilized as impediments in the stilling basin, using various layouts to dissipate excess kinetic energy. The numerical findings demonstrated that the obstacles are effective energy dissipaters, reducing the hydraulic leap length and the length of the stilling basin as a result. The best situation is to place three semi-cylindrical slices in the stilling basin, with energy dissipation ratios ranging from 48% to 63%, with an average difference of 14% from the values of classical hydraulic leaps based on discharge. It should be noticed that semi-cylindrical slices perform better. **Daneshfaraz** [14] experimented with several buffet block designs for energy dissipation. The findings reveal that using sills of maximum width (b = 0.20 m) for pyramidal, semi-cylindrical, cylindrical, and rectangular geometries increased energy loss by 125, 119, 116, and 125% in section A, respectively. The semi-cylindrical sill is most successful at boosting the discharge coefficient, whereas the pyramidal sill is most effective at increasing energy dispersion. **El-Saie et. al.** [15] Flow-3D software was used to examine the features of the forced hydraulic leap. The numerical findings revealed that the impediments have a substantial impact on enhancing flow characteristics and increasing energy dissipation. The optimal situation is to construct seven rows of circular baffle blocks staggered at equal distances in the stilling basin, with relative energy loss ranging from 50% to 60% depending on flow conditions**.**

In this study, the hydraulic jump's energy is diffused by suspending a pendulum sill downstream of the gate. The location and weight of pendulum sills are modified to determine the best position for energy dissipation under various flow conditions.

2. Theoretical approach

To analyze the problem of energy dissipation of the hydraulic leap theoretically, the following assumptions should be made: The flow is constant, water is incompressible, friction losses throughout the jump are small, pressure distribution is hydrostatic at the start and finish of the jump, and the flow upstream and downstream of the jump is roughly parallel to the bed.

Fig. 1 depicts a defining sketch for the various parameters used in this investigation.

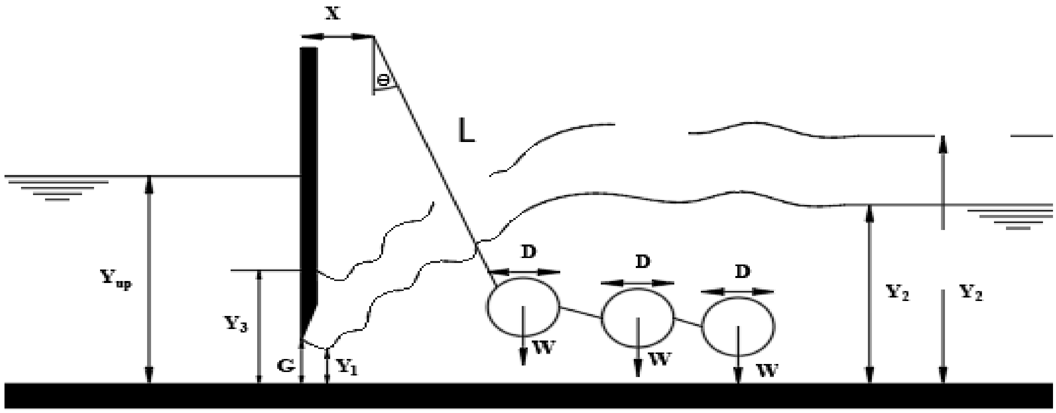

Fig. 1 Definition sketch for the studied model.

Using dimensional analysis methods, the various variables influencing energy dissipation through the spillway could be represented in the following dimensionless equation:

For the given scenario, using the concepts of dimensional analysis, the different variables controlling the energy dissipation through the spillway can be stated in the following form:

f (yup, y1, y2, y3, Lj, ɵ, V, ρ, G, μ, g, ΔE, E1, E2, D, L, X, N, W) = 0

Where G represents the gate opening, yep is the water depth upstream of the gate, y1 is the jump's initial water depth, y3 is the backup water depth downstream of the leap, y2 is the depth of water at the jump's end, and Lj is the jump length. g is the gravitational acceleration, E1 is the total energy immediately after the gate, E2 is the total energy at y2, and ΔE is the energy loss throughout the jump. The bulk density of water is denoted by ρ, and its dynamic viscosity is represented by μ. D is the cylinder's diameter, L is the string length, X is the distance between the gate and the beginning of the string length, W is the weight of the cylinder, N is the number of cylinders, and ɵ is the angle of inclination of the string length with the vertical axis.

Using Buckingham's π-theorem and repeated variables (G, v, and ρ), the general relationship between these variables can be expressed as follows:

$$\frac{\Delta E}{E_1} = f(F_G, N, \Theta, \frac{y_2}{G}, \frac{X}{G}, \frac{L}{G}, \frac{D}{G}, \frac{W}{\rho * V^2 * G^2})$$

$$W_r = \frac{W}{\rho * V^2 * G^2}$$

3. Experimental work

The experiment was carried out in the hydraulics engineering laboratory at the Faculty of Engineering at Zagazig University in Egypt.

3.1.Experimental Flume

This study employed a recirculating flume measuring 15.6 m long, 0.3 m wide, and 0.468 m deep (see Fig. 2). The sides of the flume bed are glass, and it is built of stainless steel, giving it a high level of stability and rigidity. At the bottom of the flume, a centrifugal pump recalculates the water. The water flow in the flume is controlled by a butterfly valve that may be manually adjusted. The depth of water in a flume is carefully measured using a point gauge with a scale reading of (0.001) m. The gate opening (6 cm) remains consistent throughout the procedure.

Fig.2. Laboratory Flume

3.2. Pendulum Sill models

The pendulum sills are hollow plastic cylinders 29.5 cm long with diameters of 3.75 and 5.00 cm and a wall thickness of 5 mm. The pendulum sill is suspended by a string that wraps around the hollow cylinder and is affixed above the gate. The placement of the sill in relation to the hydraulic leap was adjusted by adjusting the string length. The sill weight was adjusted to three values in each diameter by half or completely filling it. The number of sills was investigated by employing one, two, and three sills linked together by intermediate threads.

Two sets of trials totaling 105 runs were carried out. Table 1 shows the basic details of these experiments.

In set A, the trials were carried out without the use of the pendulum sill. These runs were carried out for five flow discharges to investigate the jump characteristics of these flow parameters and compare them to similar flow conditions in set B. The trials in set B were conducted using a pendulum sill. The sill was hung immediately above the bed at several longitudinal places, and the sill weights and numbers for each flow discharge are shown in Table 1. In each trial run, the flume's tank is filled with clean water, the pump is turned on, and the flow discharge is controlled using the control valve. Inset B, experiments with the sill are hung at a specific X-location, so that it rests on the bed. The tailgate determines where the leap will take place. When conditions are stable, the discharges are measured with the weir. The water surface profile between the two successive depths of the jump is measured using a point gauge. The average water velocity and total energy loss during the jump are determined. To repeat another experiment, the location of the pendulum sill is shifted longitudinally.

Table 1: Primary details of experiments.

series	$Q_{(l/s)}$	$Lx_{(cm)}$	N	$D_{(cm)}$	$W_{(gm)}$
Set A (5runs)	15.42,16.68,18.54, 19.89,20.90				
Set B (100runs)	15.42,16.68,18.54, 19.89,20.90	32 42	1 2 3	3.75 5	431,480, 596,770,1121,656

4. Analysis and discussion

To diffuse the energy of the hydraulic jump, experiments were undertaken to see how a pendulum sill with varied locations and numbers downstream of the gate would react.

4.1. Case: No pendulum sill (Classical Jump)

To ensure that the conclusions were accurate, the case of free behavior was compared with both **Hager's equation** [1] and the **Abdelmonem** results [9], as shown in the figure.

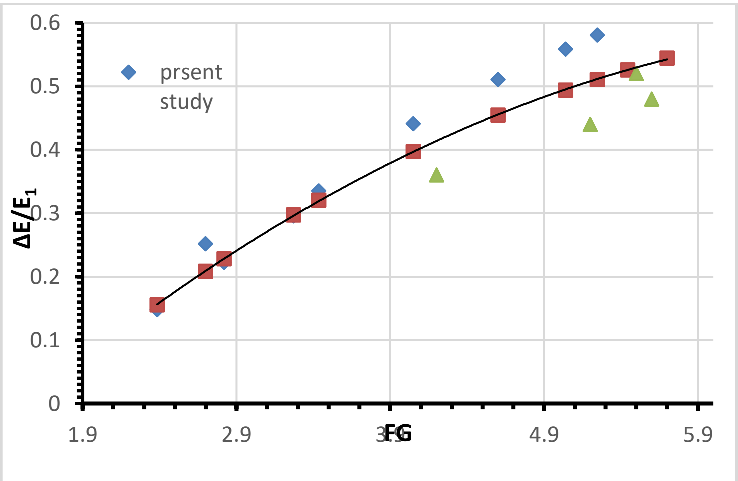

Fig. 3 Shows how the relative energy loss (ΔE/E1) varies with the supercritical Froude number. The following equation by Vischer and Hager [1] is displayed for comparison.

$$\frac{\Delta E}{E_1}=\frac{1}{8}\frac{\left(\sqrt{1+8F_1^{\,2}}-3\right)^3}{\left(2+F_1^{\,2}\right)\left(\sqrt{1+8F_1^{\,2}}-1\right)}$$

The image illustrates a good agreement between Eq. (1) and the experimental results from this investigation. The error between the results of this experimental research and Hager's equation was around 12%.

4.2. Case: Using a Pendulum Sill

This subsection investigates the influence of string length and number of cylinders on energy dissipation downstream of the sluice gate.

4.2.1. Studying the effect of changing the string length

Figures from 4 to 9 show the correlations between relative energy dissipation and gate Froude number for various string lengths. These data show that as the gate Froude number increases, so does the energy dissipation. Increasing the string length enhances energy dissipation, regardless of the cylinder's weight or diameter.

Observing the placement of the cylinder in both situations, it was discovered that in the shorter string length scenario, the cylinder was in the middle third of the hydraulic leap, while in the longer length, it was in the final third. However, due to restrictions in available discharges and channel dimensions, it was impossible to repair the cylinder during the first third. Thus, by comparing the effect of the cylinder in the two locations, it was discovered that the last third has a greater effect than the middle third because the effect of the cylinder is similar to the effect of the end sill, and thus it is more effective in dissipating energy than the middle third under the studied flow condition.

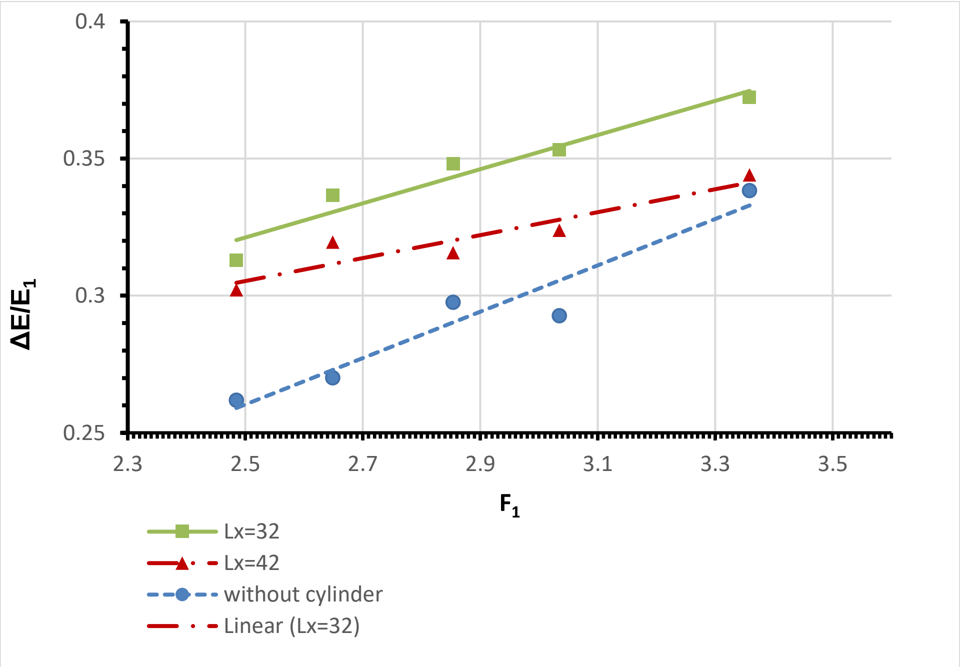

Fig.4.The relationship between gate Froude number (F1) and relative energy dissipation (ΔE/E1) for varied string lengths (L/G) with a constant W=431 and D=3.75.

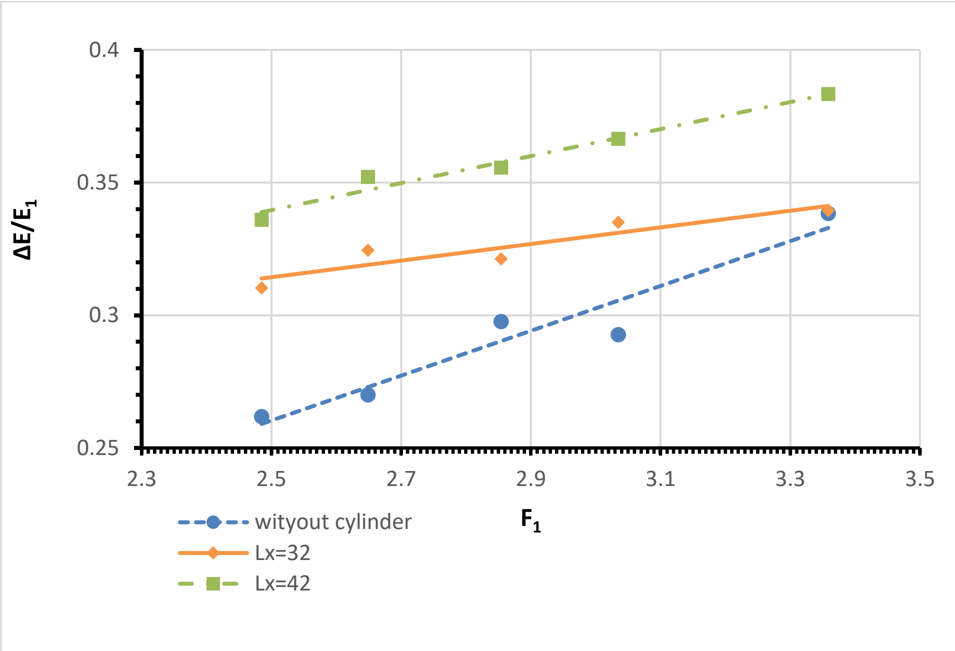

Fig.5.The relationship between gate Froude number (F1) and relative energy dissipation (ΔE/E1) for varied relative string lengths (L/G) for constant W=480 and D = 3.75.

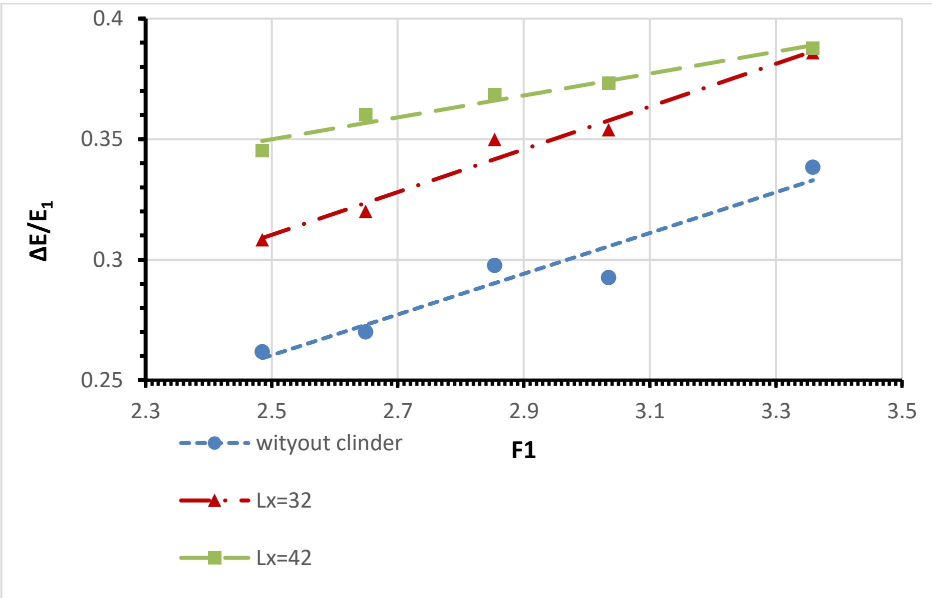

Fig.6.The relationship between the gate Froude number F1 and the relative energy dissipation ΔE/E1 for varied relative string lengths Lx/G for constant W=596 and D=5.

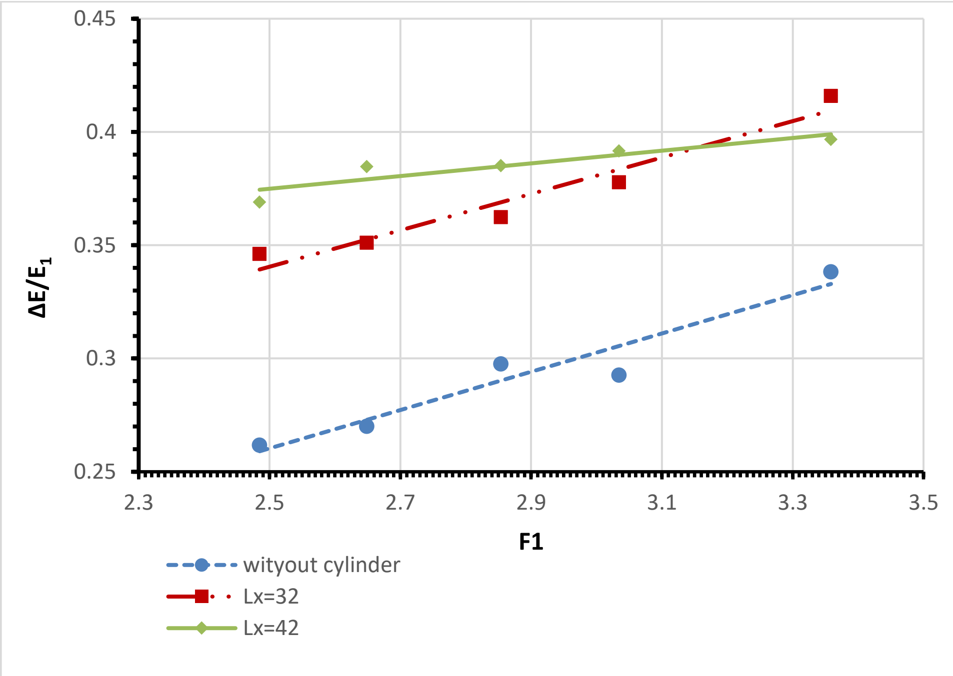

Fig.7.The relationship between gate Froude number (F1) and relative energy dissipation (ΔE/E1) for varied string lengths (L/G) at constant W = 770 and D = 5.

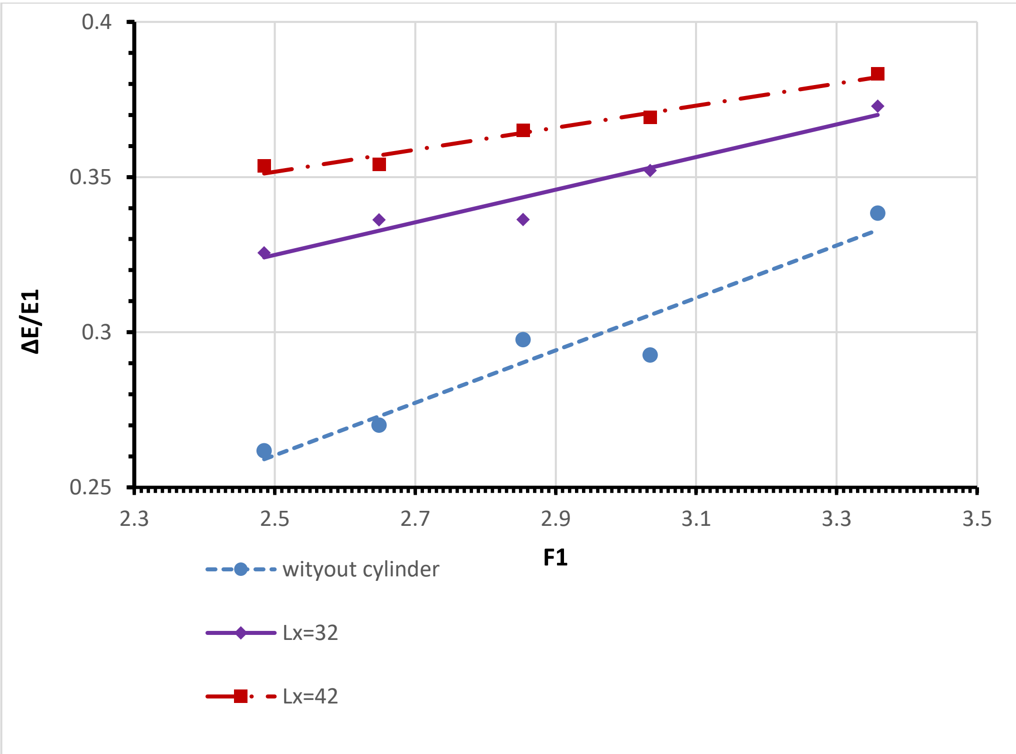

Fig.8.The relationship between gate Froude number (FG) and relative energy dissipation (ΔE/E1) for varied string lengths (L/G) for constant W = 656 and D = 3.75.

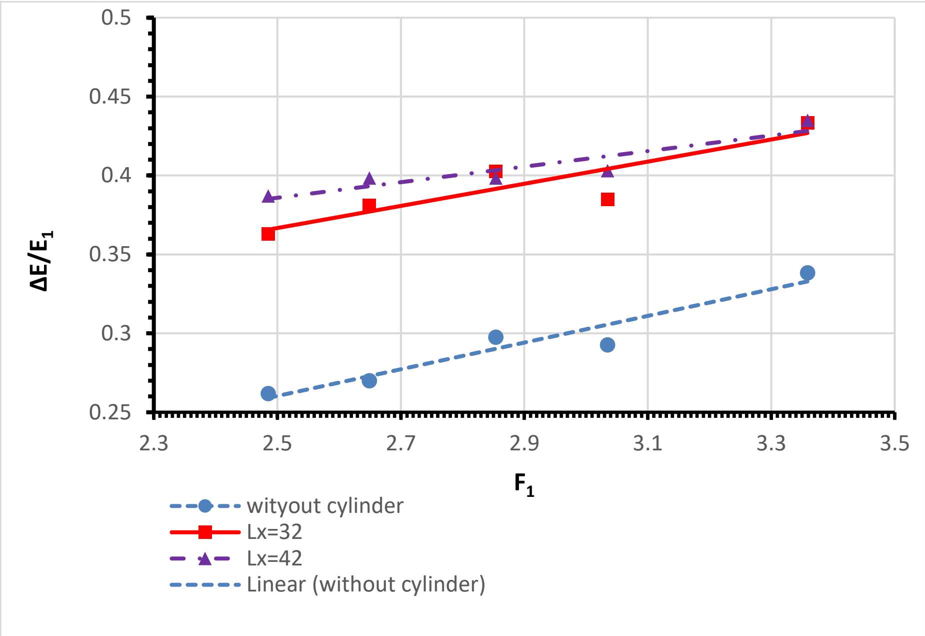

Fig.9.The relationship between gate Froude number (FG) and relative energy dissipation (ΔE/E1) for varied string lengths (L/G) with constant W=1121 and D=5.

4.2.2. Studying the effect of changing the cylinder weight

Figures 10, 11, and 12 depict the correlations between relative energy dissipation and gate Froude number while adjusting the cylinder weight. These data show that as the gate Froude number increases, so does the energy dissipation.

It was discovered that increasing the weight increases energy dissipation by a significant percentage, regardless of string length or cylinder diameter. This is due to the weight component, which increases the cylinder's stability during the hydraulic leap, increasing the reverse shock of the water and, as a result, energy dissipation.

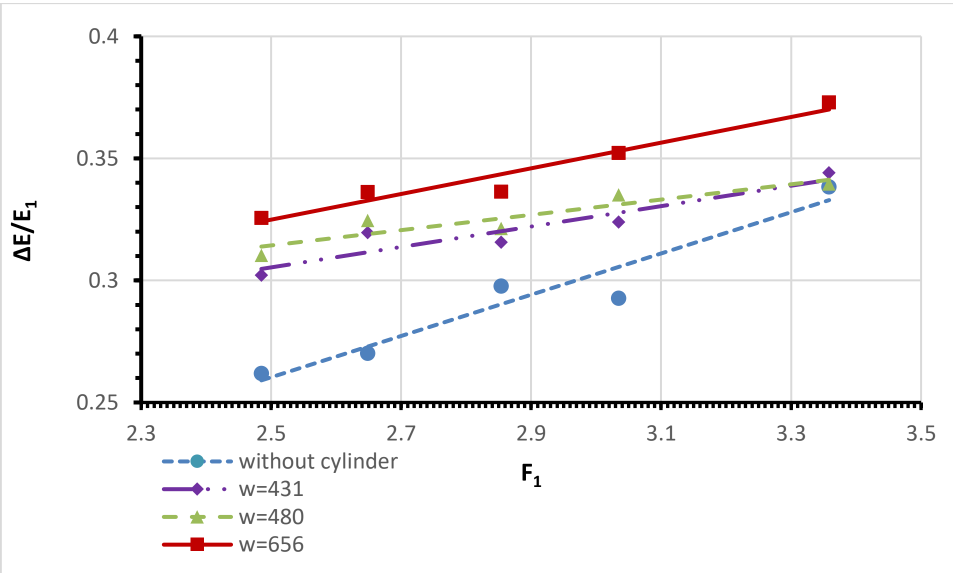

Fig.10.The relationship between gate Froude number (F1) and relative energy dissipation (ΔE/E1) for varied cylinder weights (W/G) at constant Lx = 32 and D = 3.7

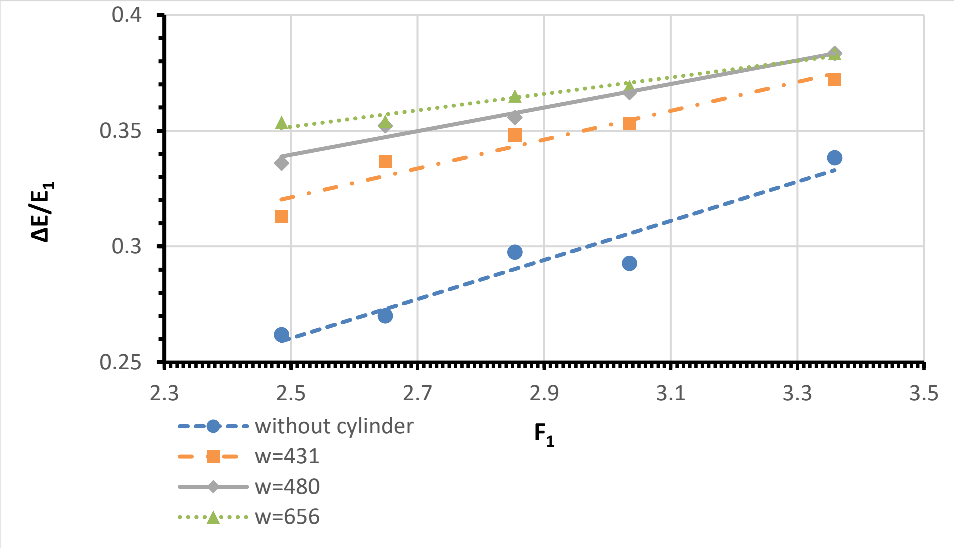

Fig.11.The relationship between the gate Froude number F1 and the relative energy dissipation ΔE/E1 for varied relative cylinder weights W/G for constant Lx = 42 and D = 3.75.

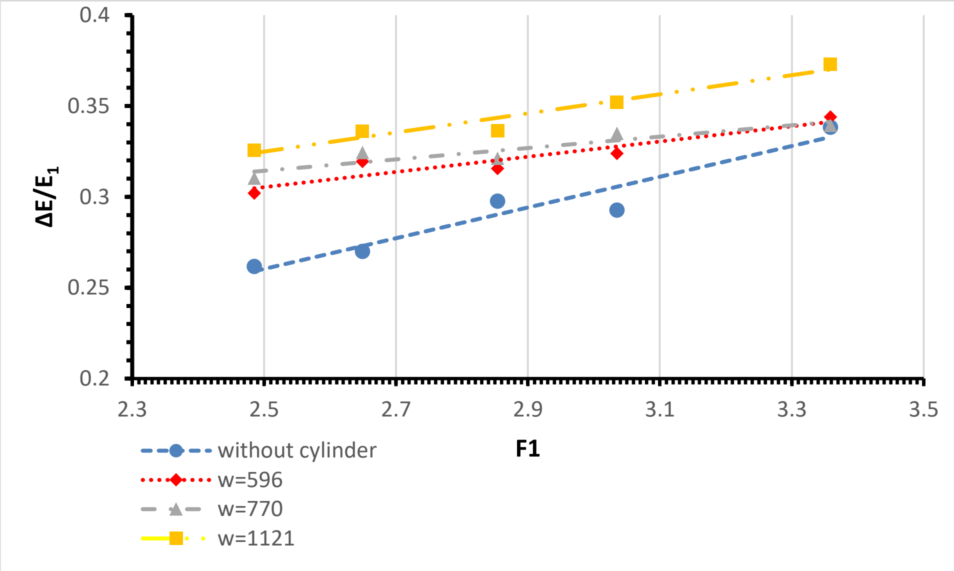

Fig.12.The relationship between the gate Froude number F1 and the relative energy dissipation ΔE/E1 for varied relative cylinder weights W/G at constant Lx=32 and D=5.

4.2.3. Studying the effect of changing the cylinder diameter

Figures 13 and 14 show the correlations between relative energy dissipation and gate Froude number when increasing the cylinder diameter. These data show that as the gate Froude number increases, so does the energy dissipation.

For two different diameters and a fixed weight, it was discovered that the influence of the diameter on energy dissipation is nearly equivalent, regardless of the variation in suspension rope length. As a result, it may be essential to investigate more diameters throughout a wider range of alterations.

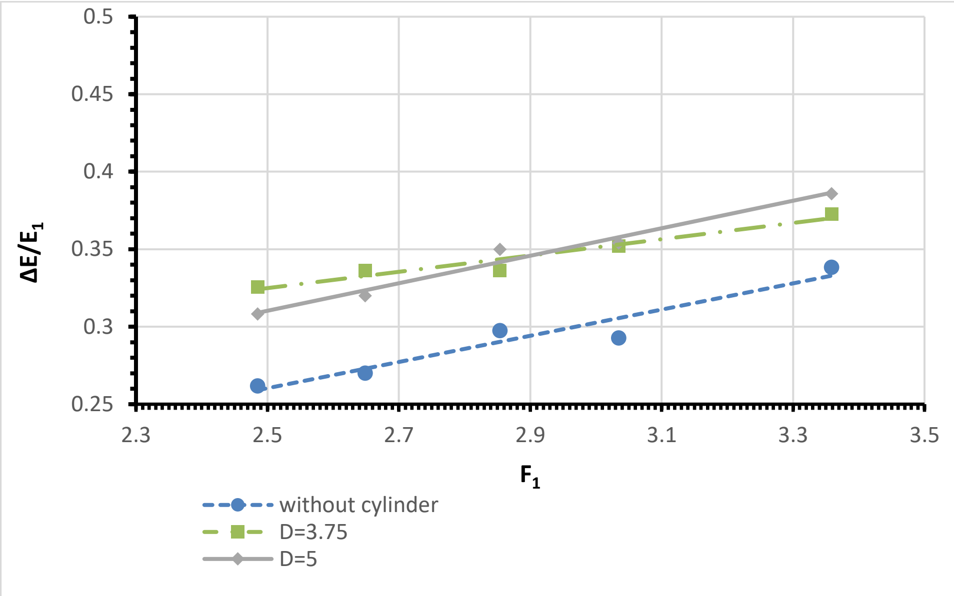

Fig.13.The relationship between the gate Froude number F1 and the relative energy dissipation ΔE/E1 for varied cylinder diameters D/G at constant Lx=32.

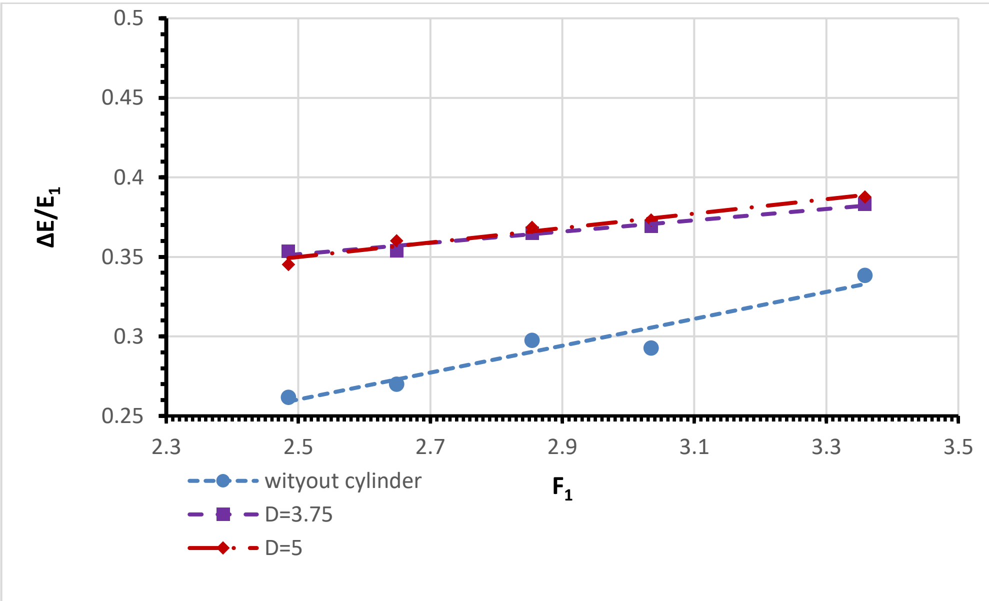

Fig.14.The relationship between the gate Froude number F1 and the relative energy dissipation ΔE/E1 for different cylinder diameters D/G at constant Lx=42.

4.2.4. Water surface profiles

Fig. 22 depicts the water surface profile along the jump length for the same gate opening and a discharge of 16.50 L/s; hence, the gate Froude number, FG, is 1.41 for the cases with no pendulum sill and those with pendulum sills at different X-locations. The results revealed that in the event of a free hydraulic jump, the water profile retains its natural shape with no discernible fluctuation. The results for all cases of pendulum sills revealed a typical leap and a clear disturbance, but the most impacted case was L=42, N=3, where the water level along the area was higher than in all cases. This is due to the distance of the first cylinder from the gate opening, as well as the number of cylinders (3), which results in what appears to be an obstacle in the path of the water due to the high levels above it, as well as the presence of a backwater carve that reaches the gate and causes the highest rate of immersion. According to these findings, despite their influence, there is a favorable effect on dispersing energy, but it will alter the length of the basin used behind the gate.

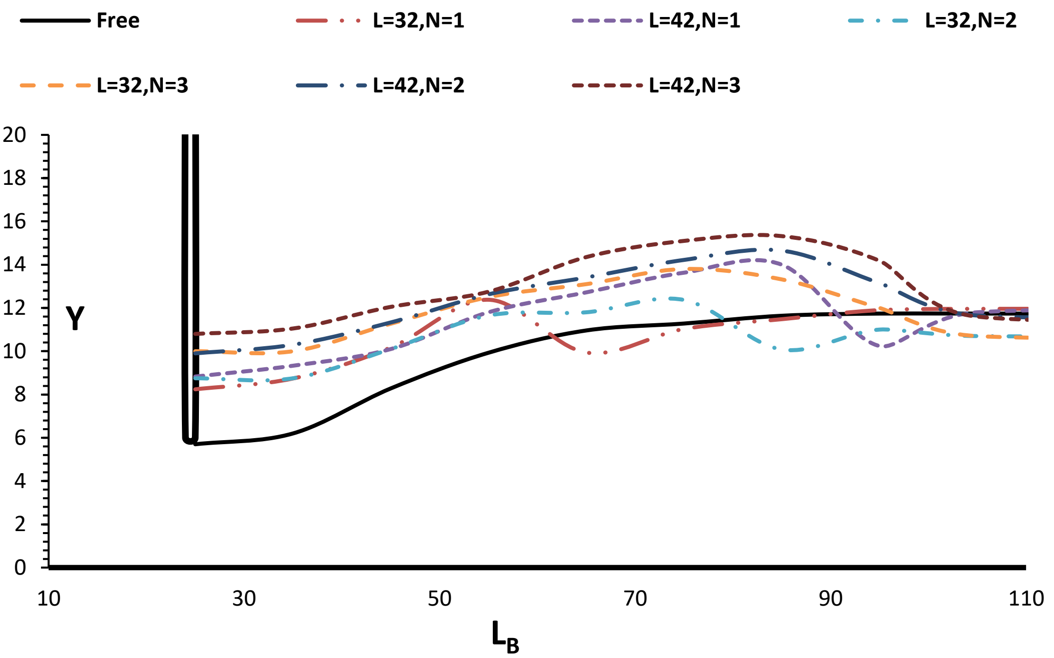

Fig.15. surface water profile for all cases at F_G=1.41

5. CONCLUSION

In this work, the influence of pendulum sill number and string length on energy dissipation was investigated. The performance of the pendulum sill was tested experimentally.

The study of the experimental data yielded the following conclusions:

1.Increasing the string length increases energy dissipation, regardless of the cylinder's weight or diameter.

2. Increasing the weight increases energy dissipation by a significant percentage.

3. For two different diameters and a fixed weight, it was discovered that the effect of the diameter on energy dissipation is nearly similar.

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