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The Effects of Different Shaped Baffle Blocks on the Energy Dissipation

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Abstract

Stilling basins can be defined as energy dissipaters constructed of the irrigation systems. This study aims at investigating the performance of the new seven baffle blocks design in terms of reducing the dimensions of stilling basins in irrigation systems. In order to assess the hydraulic efficiency of a new model for baffle block used in stilling basins, a Naval Research Laboratory (NRL) has conducted. The results of this study demonstrate that the performance of the new baffle block, in term of hydraulic jump length reduction and hydraulic energy dissipation, it's better than standard blocks. However, the ratios of the drag resistance attributed to the new baffles block (F_B / F_2) have been larger than that applied on the normal block. It was found that the new block dissipates the energy by 9.31% more than the concrete block, and decreases the length of the hydraulic jump by 38.6% in comparison with the standard blocks. However, the new block maximizes the drag force ratio by 98.6% in comparison with the standard baffle blocks. The findings indicated that in terms of energy reduction and dissipation in the length of the hydraulic jump, the new block is superior to the other kinds.

Keywords: Baffle Blocks; Stilling Basins; Energy Dissipation; Spillway; Hydraulic Jump.

1. Introduction

Stilling basins can be defined as energy dissipaters constructed downstream of the irrigation systems (such as chutes and spillways). The dimensions of these dissipaters mainly depend on the hydraulic jump characteristics. Normally, the stilling basins have large dimensions, which means they require large areas and the construction costs are high. For example, Samadi-Boroujeni et al. (2013) investigated the characteristics of hydraulic jump in a rectangular cross-section flume over six triangular corrugated beds. Results showed that the folded bed influenced the conjugate depths of the hop and the water-powered hop length to be reduced by 25% and 54.7% separately [1]. The creators showed that the amazed beds were superior to the separated ones as far as diminishing the sequent profundities and length of bounce. As of late, the idea of astound squares has been utilized in cutting edge water treatment units to blend water and disseminate the unreasonable vitality [2-5].

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In the skimming flow regime, enhanced energy dissipation has been studied by many researchers who focused on stepped chutes operating, such as Takahashi and Ohtsu (2012), Hunt et al. (2014) and Chanson (2015) [6-9]. Specific characteristics of stilling basins *Type III* at the ends of steeply sloping stepped chutes were investigated by several researchers, such as Meireles et al.(2014) [10]. The major results of this study are that the hydraulic jump downstream of a stepped chute stabilized much faster than in a *Type I* stilling basin. Several empirical methods are available to provide the sequent depths and Froude number at stilting basins [11-13].

Ellayn and Sun (2012) showed that relative to those with flat floors, the change in the duration of the leap and the ratio of the longitudinal depths are 30 to 50% and 16.5 to 30% respectively. In this analysis, the importance of Reynold's number (Re) can be ignored since, as in Abdeen et al. (2015), the viscous force usually has an almost negligible effect in hydraulic jumping and open path [14, 15]. Ezizah et al. (2012) studied the impact on the hydraulic jump length of the increase in strength and roughness length parameters [16]. Valero et al. (2015) have recently numerically analyzed the effects of chute blocks on both the length and stability of the hydraulic jump for both adverse conditions and design. The model established showed a good ability to replicate the change in the stability and length of the hydraulic jump [17].

Tiwari et al. (2011) reviewed the impact of end sill on the performance of non-circular pipe outlet models in the stilling basin. The authors found that under the same flow conditions, the triangular end sill has a better performance than other end sill types [18]. Some previous studies have also announced comparative perception, Tiwari et al. (2013) deconstructed the hypothetically and experimentally submerged water-driven bounce framed in an outspread stilling basin furnished with a sudden drop. The authors have identified that the sill reduces the heaviness of the gate and operation constrain, and then the gate turns out to be more monetary [19].

Abdelhaleem (2013) performed the prediction of the downstream scour geometry of a Fayoum style weir and the minimization of the scour using a semi-circular block row. The method discussed in this study is anything but hard to use as an external part of existing water systems in order to limit downstream scouring of these structures. Including various statures and positions of puzzle obstructs of various stream situations, a hundred and 53 runs are performed. An instance of a level floor without confuses was observed for the test program to measure the impact of using the bewilder docks. The results are analyzed and graphically presented, and the scour parameters were measured with clear formulae [20].

Mohamed et al. (2015) focused on the experimental study of the impact of the sill over the case study Nagaa Hammadi regulator stilling basin on the duration of the reverse flow behind the sill, the pace at the end of the stilling basin, the dissipation of water, the length of the submerged hydraulic hop and the shape of the scour downstream regulator apron. It is observed that the sill over the stilling basin has a great effect on the characteristic of the flow and the depth of the local scour shaped downstream operator, especially for the upstream and downstream sill with correct and slopped faces. It also indicates that, as the submersion ratio and the Froude amount rise, the reverse flow length downstream sill decreases. Additionally, utilizing sill with correct upstream and slopped downstream face with L_s/ L=0.6 cuts the duration of the submerged hydraulic hop by a total of 59 percent, contributing to a reduction in the length of the stilling lake. The Regional depth of scouring downstream hydraulic systems has been decreased by 43% [21]. In addition, Elsaeed et al. (2016) investigated the effect of calming basin shapes with different end-stage heights on the characteristics of the submerged hydraulic jump and the energy dissipation downstream of the radial gate and obtained a clear match of the results from the length of the velocity analysis and jump [22].

Abdelhaleem (2017) experimentally investigated the submerged flow through radial gates with and without a gate sill. He finished up the negative impact of sills under submerged radial gates and legitimized the nearby scour marvels that occurred promptly downstream the stilling basin of some current submerged radial gates with a gate sill in Egypt [23].

For submerged hydraulic jumps with cylinders, Alirezaet et al. (2014) studied the time-averaged properties of the two flow regimes. The mean stream area, the root of the maximum longitudinal velocity and mass vitality dispersal were investigated and the redirected surface fly (DSJ) method was seen to be more effective than the re-attaching divider fly (RWJ) stream systems in that the longitudinal portion of the velocity and dispersing the overabundance vitality of the approaching current; This study obtained a wide range of stream criteria, but the mid-value of quantities by program was reduced to time-finding. This information could then not be used to evaluate the choppiness spatial and temporal properties within the two stream structures. Such a knowledge collection; for example, spatial and transient time arrangement within a submerged hop with squares of the aggressive stream property [24].

An experimental study was conducted by Ibrahim (2017) to explore the impacts of block shapes on the downstream flow pattern of a radial wall, the tests showed that the blocks had a strong ability to limit the disconnected effect of the downstream flow pattern [25]. According to the study of Ali et al. (2018), which found that using the baffle block induced a decrease in the sequential depth ratio, the duration of the hop ratio and the length of the roller, but the energy dissipation ratio improved [26]. Jaafar et al. (2018) stated that the best performance could be obtained with the use of two row design of regular USBR baffle blocks with a blockage ratio of 50 and 375 percent, respectively, and at defined distances by the sequential depth next to the velocity to be spread almost evenly across the basin range [27]. Al-Husseini (2016) demonstrated that the dissipation of flow energy declines as the flow rate rises, and the rough phase spillway surface is more efficient compared to other low or high flow surfaces [28].

In this context, the current study focused on investigating the performance of the new design of seven baffle blocks in terms of reducing the dimensions of stilling basins in irrigation systems. Additionally, the performance of these new baffle blocks has been compared to the performance of standard types of baffle blocks. In order to assess the hydraulic efficiency of a new design for baffle blocks used in stilling basins, a naval laboratory study was carried out. This experimental seven blocks performance was contrasted with normal trapezoidal blocks performance. Using the dimensional analysis technique, the dimensional parameters of the hydraulic performance of the new baffle block and the drag force used were analyzed.

2. Material and Methods

2.1. The Studied Baffle Blocks

A new seven baffle blocks with standard trapezoidal baffle block have been manufactured, at the University of Babylon at the Laboratory of the Faculty of Engineering, using local wood according to U.S.B.R recommendations. Then, these blocks were painted using a waterproof paint to prevent water leakage that could distort their shape. The studied traditional type of baffle block has a trapezoidal-shaped section with external dimensions of 6.2 cm in width and 5.5 cm in height. The internal sides are inclined by 9^o, which makes the net height of the short side 3.5 cm, Figure 1 (A). The new seven baffle blocks were a V-shaped block with an interior angle of 30^o (V30) (vertical and horizontal angle), a V-shaped block with an interior angle of 20^o (V20) (vertical and horizontal angle), a V-shaped block with an interior angle of 10^o (V10) (vertical and horizontal position), and Semi-Cylinder block (SC).

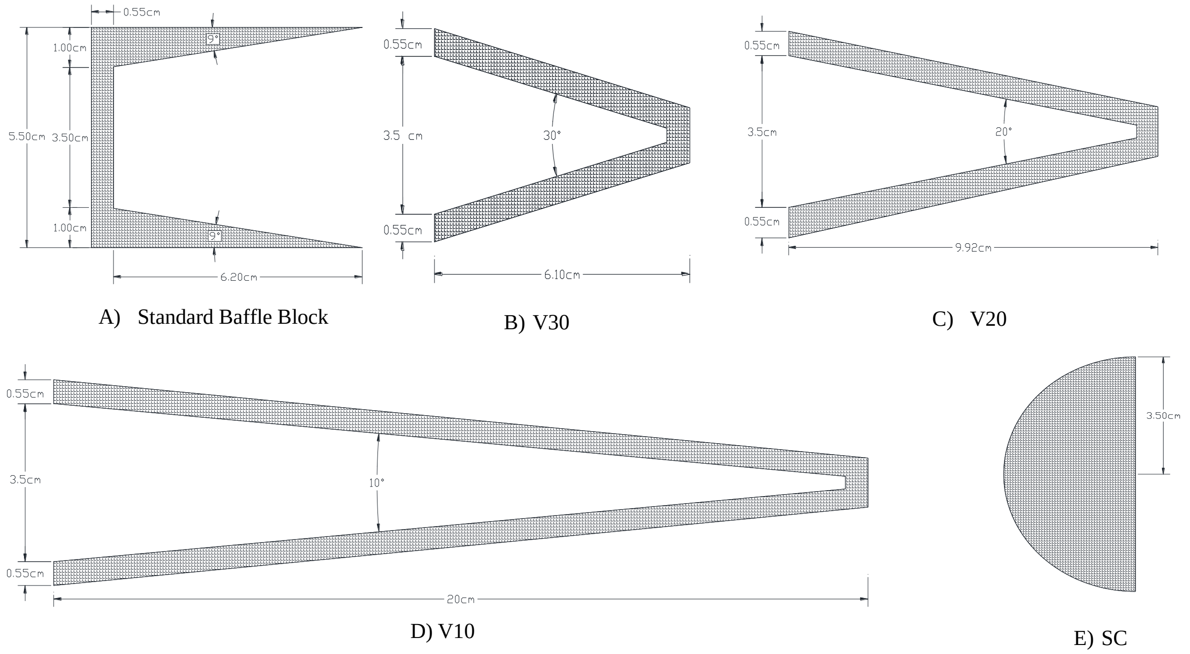

Figure 1. The Studied Baffle Blocks

2.2. Experimental Set Up

Experimental work was carried out using a rectangular open tilting flume made from Perspex. The flume is 17.50 m in length, 0.30 m in depth and 0.30 m in width, and has a bed slope of 1:6. It is supplied with a spillway, 0.355 m in stature, installed at 6.50 m upstream of the flume. Water depth and scour opening have measured by utilizing points gage, with accurateness of 0.1 mm, mounted on an aluminum frame that could be moved in both directions, vertically and horizontally along the bed of the flume. The scour gap area and length were accurately measured using a scale installed on the flume inner wall. The downstream water depth was controlled by a tailgate. The Plan and location of the baffle of the flume are shown in Figures 1 and 2. It is located after spillway location about 0.5 m.

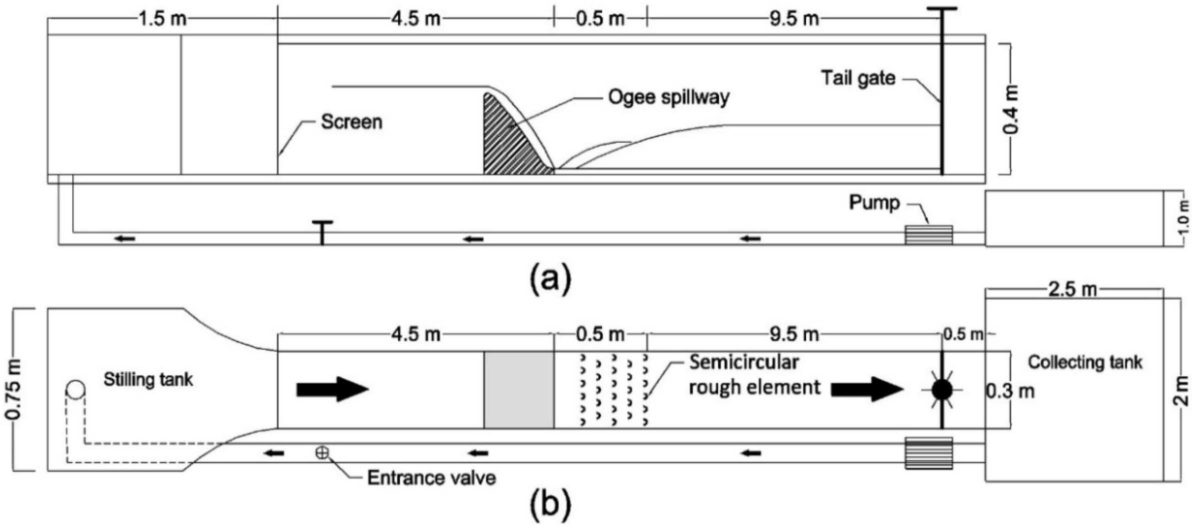

Figure 2. Experimental flume (a) Longitudinal section view and (b) Plan view [31]

2.3. Theoretical Approach

The experimental work was initiated by installing three blocks of each of the seven types of baffle blocks inside the flume. Then, the following parameters were measured under different discharge rates between (18 and 28) l/s to ensure an initial Froude number between (6.5 and 9.2):

1) Discharge and Water depth before ogee spillway;
2) Water depth before hydraulic jump (Y_1);
3) Water depth after hydraulic jump (Y_2);
4) Length of hydraulic jump (L_j);
5) The initial (V_1) and final (V_2) velocity at Y_1 and Y_2 respectively.

The following procedure and calculations should be performed:

1. Check the accuracy of both the initial (V_1) and final (V_2) velocities by applying continuity equation:

$$V = Q/YB \tag{1}$$

Where: V= initial and final velocity (m/s); Q= discharge (m^3/s); B= flume width (m); and Y= depth of flow (m).

2. Compute the velocity heads (h_{v1}, h_{v2}) from the Equation 2:

$$h_v = v^2/2g \tag{2}$$

Where: h_v= velocity head; h_{v1}, h_{v2} before and after hydraulic jump (m), V= velocity (m/s), g= acceleration (m/s^2).

3. Compute the initial and final Froude number:

$$Fr_1 = V_1/(gY_1)^{0.5} \tag{3}$$

$$Fr_2 = V_2/(gY_2)^{0.5} \tag{4}$$

Where: F_{r1} and F_{r2}= initial and final Froude number (dimensionless), respectively; V_1 and V_2= initial and final velocity (m/s); and Y_1 and Y_2= Water depth before and after hydraulic jump (m) respectively.

4. Compute the total energy at position Y_1 and Y_2:

$$E_i = Y_i + V_i^2/2g \qquad i = 1, 2 \tag{5}$$

Where: E_i= kinetic energy at position Y_1 and Y_2 (m); Y_i: Water depth before and after hydraulic jump (m); V_i= initial and final velocity (m/s).

5. Compute dissipated kinetic energy (ΔE):

$$\Delta E/E_1 = (E_1 - E_2)/E_1 \tag{6}$$

Where: ΔE= dissipated kinetic energy (dimensionless); E_1= kinetic energy before hydraulic jump (m); and E_2= kinetic energy after hydraulic jump (m)

6. Compute pressure force of water behind hydraulic jump F_B:

$$\gamma.\frac{Y_1^2}{2} - \gamma.\frac{Y_2^2}{2} - \frac{Fb}{B} = \rho.V_2^2.Y_2 - \rho.V_1^2.Y_1 \tag{7}$$

Where: F_B: pressure force (kN), γ and ρ are weight and mass density (kN/m^3, kg/m^3), respectively.

7. Compute drag force (F_2):

$$F_2 = \gamma\, Y_2^2/2 \tag{8}$$

Where: F_2= drag force (kN); γ= weight density (kN/m^3); Y_2 =Water depth after hydraulic jump (m).

Although other variables that influence the drag force it is mainly influenced by the depth of the water. Thus, during the experimental work, the impact of this factor was considered in the current study. Drag force on baffle blocks (dissipated kinetic energy (ΔE) is a function of different variables; therefore, a dimensional analysis was conducted to generate non-dimensional equations, which in turn are functions for the ratio of (ΔE/E1) or (FB/F2) where flow is turbulent in all laboratory experiments [29, 30]. The following equations show the non-dimensional variables:

$$f_1(Fr_1, Fr_2, w/h_b, X_b/h_b, L_j/Y_1, \tan\theta_h) = 0 \tag{9}$$

$$f_2(Fr_1, Fr_2, w/h_b, X_b/h_b, L_j/Y_1, \tan\theta_v) = 0 \tag{10}$$

$$f_3(Fr_1, Fr_2, w/h_b, X_b/h_b, L_j/Y_1, r/h_b) = 0 \tag{11}$$

Where: F_{r1}= Froude number upstream of the jump; F_{r2} = Froude number downstream of the jump, F_2 = drag force (kN), w :width of baffle blocks (m), X_b= distance between baffle blocks and initial of hydraulic jump (m), h_b= height of baffle blocks (m), (L_j)= Length of hydraulic jump (m), Y_1= Water depth before hydraulic jump (m), r= radius of cylinder baffle blocks (m); and (θ_h, θ_v)= horizontal and vertical positions, respectively (degrees).

3. Experimental Procedure and Measurement

Seven various forms of baffle piers have been examined downstream of the spillway models as energy dissipators. There have been a total of 120 races. Consideration was granted to six separate discharges (Q= 19.62, 17.75, 16.33, 12.5, 10.7 and 6.50 l/s). The spillway was used for each release one fixed water depth Y_2 downstream. All the models used were arranged in the flume to have almost a comparable conduit that was roughly 40%. The downstream water depth is the column area of the perplex wharfs model from the toe of the spillway (X_0) and (Y_2). The operation courses and dimensions of the spillway and various flume parts are shown in Figure 1. Point by point and course of action of the tried and tested amazing models are shown in Figure 2.

Since the hydraulic jump in the stilling basin should be formed steadily for the given discharge, the Froude number of the approaching stream Fr_1 should be confined to prevent the deep waviness and precariousness of the water surface. Tests of the research facility show that if Fr_1 reaches 6.5 to 9.2.

Runs were started with a first feeding backwater until the depth of the downstream water reaches higher than the desired water depth of some discharge. Then, step by step, the upstream bolstering was started and balanced at that point. The back end was brought down slowly until the perfect downstream water depth Y_2 was collected. When there were no significant differences in measures of scour gap (it was seen from this research work that a run took around 2 hours to reach a safe condition); the flume delta bolstering valve was shut down. Finally measurements of scour opening were determined using a point test and scale.

The water level calculations were made in the flume's three dimensional axes. The hydraulic characteristics, dimensions, and spacing of each individual baffle block are identical for a comparative performance between the tested baffle blocks. To insure so, downstream water levels are raised, just as the pipeline is held steady to seek. For each perplex rectangle, the go of the conduit is about 40 percent. The conceptual models of bewildering docks that have bended surfaces give the impression that they are not constructible, yet they are feasible that they are effectively created from cement or steel. Again, the aim of this investigation is to propose another bewildering squares, but in addition to improving each other effectiveness. Figure 3 shows how to calculate the how to calculate hydraulics jump length. Figure 4 shows experimental procedure of this study

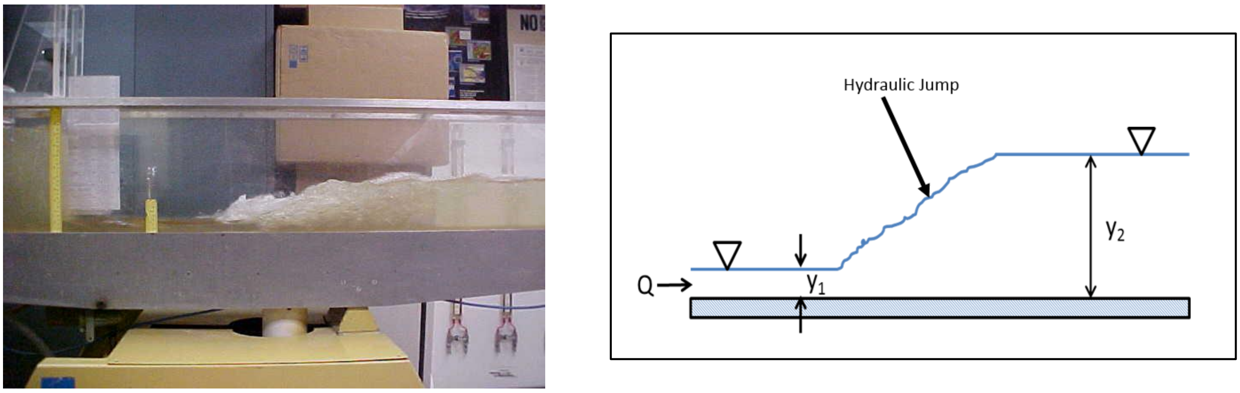

Figure 3. Calculate Hydraulic Jump Length

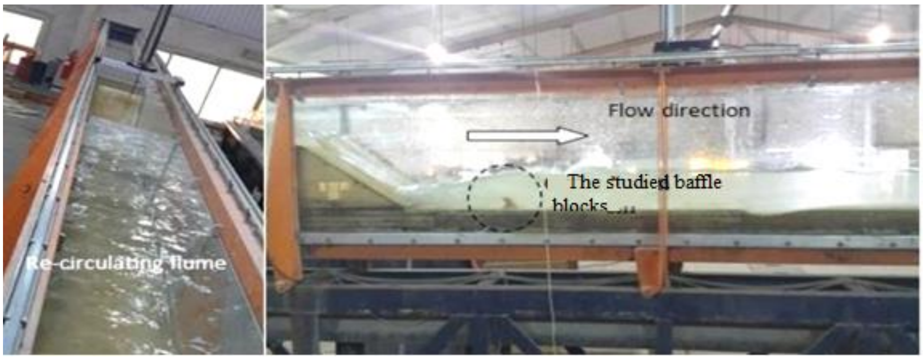

Figure 4. Selected photos from experimental procedure

4. Results and Discussion

The effect of the form of the baffle blocks on the dissipation of electricity, the ratio of reduction in the duration of the hydraulic hop, and the ratio of the applied drag force on the baffle blocks was determined using Equations 9 to 11 at X_b/Y_1.

4.1. Ratio of Kinetic Energy Dissipation

The experimental work was initiated using the new shapes of blocks (V10, V20, and V30). These V-shaped blocks were installed in two different positions: horizontally and vertically. For the horizontal position, Figure 5 shows the relationship between the slope of the V-shaped baffle blocks and the ratio of energy dissipation for Froude numbers ranging between 6.5 and 9.2. It can be seen from this figure that the larger the slope of the block, the greater the dissipation of energy for all Froude number values. For example, at Fr= 6.5, the energy dissipation increased from 2.42 to 7.09% as the slope increased from 10 to 30º.

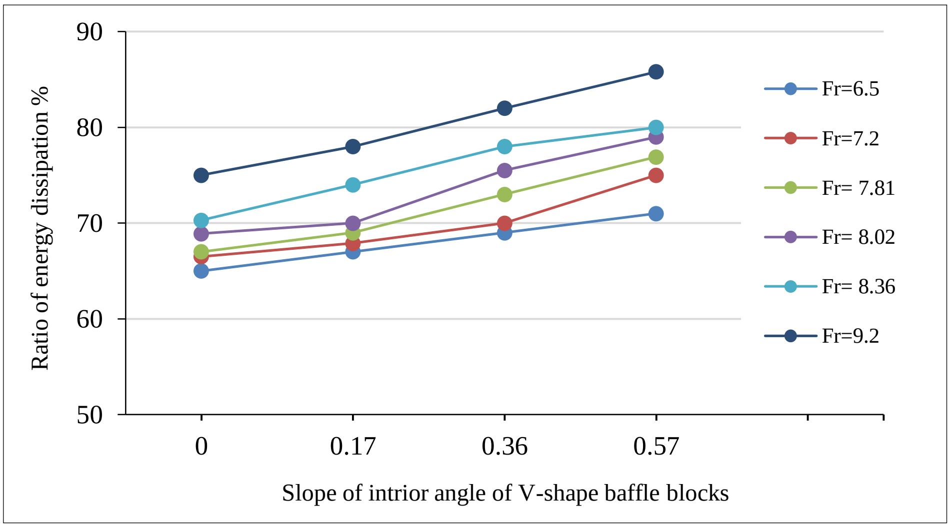

Figure 5. Relationship between slope of the interior angle of the V-shaped baffle blocks and ratio of energy dissipation (in a horizontal position)

A similar relationship between the slope value and the energy dissipation was noticed in the vertical position, as shown in Figure 6. For instance, at Fr = 6.5, the ratio of energy dissipation increased from 2.62 to 7.93% as the slope increased from 10 to 30º. However, it can be seen from Figures 5 and 6 that the energy dissipation ratio at the vertical position was greater than that at the horizontal position. For example, at Fr = 6.5 and slope of 30º, the energy dissipation ratio increased from 7.09% at the horizontal position to 7.93% at the vertical position. As a compared with Hayder (2017) which explain the average values of energy dissipation were computed and found to be 68.1% and 60.4% for semi-circular rough elements and stilling basin *Type I*, respectively [31]. The semi-circular elements model M1 gave good results of reducing the scour-hole and consequently has good energy dissipation compared to most of the other models tested by Bestawy (2013) [32].

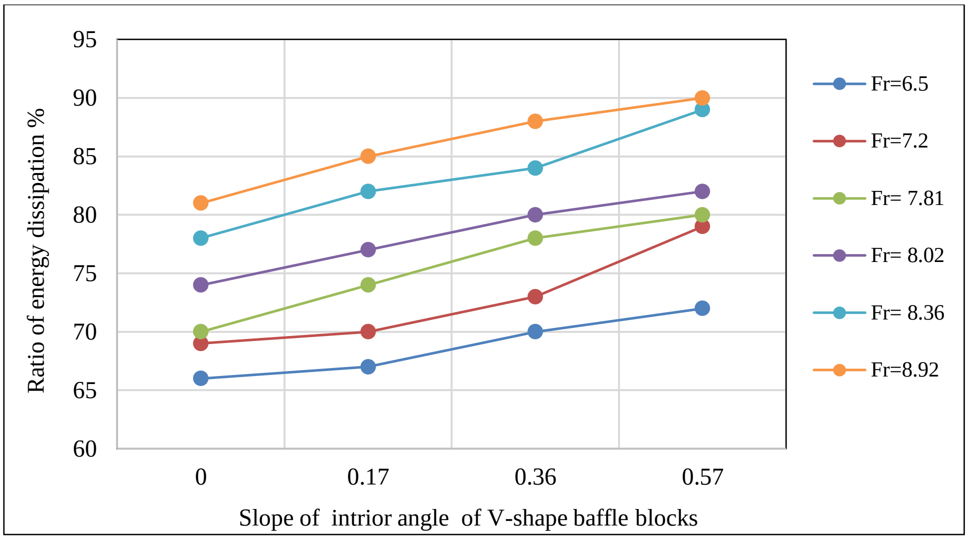

Figure 6. Relationship between slopes of the interior angle of the V-shaped baffle blocks and ratio of energy dissipation (in a vertical position)

Again, a similar trend was observed in the semi-cylinder baffle blocks in both vertical and horizontal positions, where it can be seen from Figure 7 that the energy dissipation ratio increased with the increase in the slope value for all Fr values. The gap between the vertical and horizontal locations was very minimal because the vertical portion of the flow will be mirrored at an angle of 180^{o} in the semi-cylinder baffle plates, i.e. the part will fully reflect the flow path causing high turbulence in the fluid.

According to Abbas et al. (2018) [33] which describes the energy dissipation ratio ($\Delta E / E_1$) reduced by using the adverse slope instead of the horizontal slope, but using the double row of the baffle model (D) at the adverse slope to increase the efficiency of the stilling basin and to convert the energy dissipation reduction to benefit, the average gain in the slope (-0.06) ratio ($\Delta E/E_1$) reaches about 10.7% when using a double slope model (D) baffle instead of a smooth horizontal bed. But Jaafar and Maatooq (2018) [34] show that the double rows of the baffle block with a blockage ratio of 50 % and 37.5 %, respectively, were very successful in improving the hydraulic jump properties and, thus, the quieting basin efficiency.

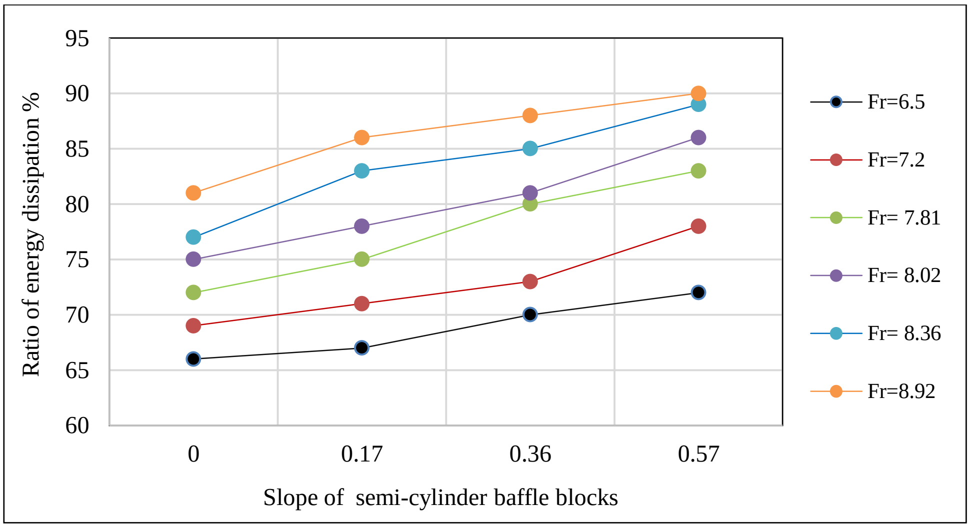

Figure 7. The relationship between slopes of the semi-cylinder baffle blocks and ratio of energy dissipation

4.2. Reduction of Hydraulic Jump Length

Figure 8 shows the relationship between the slopes of the baffle block slopes, in the horizontal position, with the ratio of L_j/Y_1 for Fr ranging between 6.5 and 9.2. A reverse relationship can be noticed between the length of the hydraulic jump and the baffle block slopes for all the studied values of Fr. For example, at Fr = 6.5 and horizontal position, the ratio of L_j/Y_1 has decreased from about 18 to 9% as the slope increased from 10 to 30º.

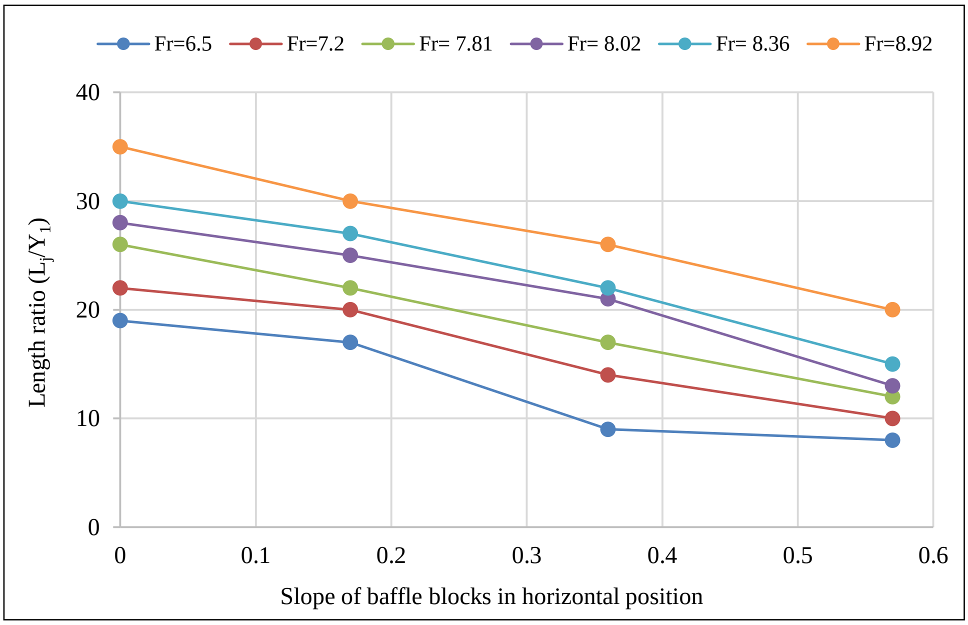

Figure 8. The relationship between slopes of the V-shaped baffle blocks, in a horizontal position, and ratio of L_j/Y_1

Figure 9 shows the relationship between the slopes of the baffle blocks, in the vertical position, and the ratio of L_j/Y_1 for F_r ranging between 6.5 and 9.2. Again, a reverse relationship can be noticed between the length of the hydraulic jump and the baffle block slopes for all the studied values of F_r. as a compared with Abbas et al, (2018) the reduction in the hydraulic jump length is greater than 15% compared to that of the Lozenge type with the same conditions of Froude number range which was used by Bejestan and Neisi (2009) [33, 35]. As compared with Jaafar and Maatooq (2018), the average reduction in (Y_2/Y_1) ratio reaches to 18.3 %, while the average reduction in (L_j/Y_1) ratio reaches to 38.1% when the double baffle model (D) at the adverse slope (-0.06) used instead of the horizontal smooth bed [34].

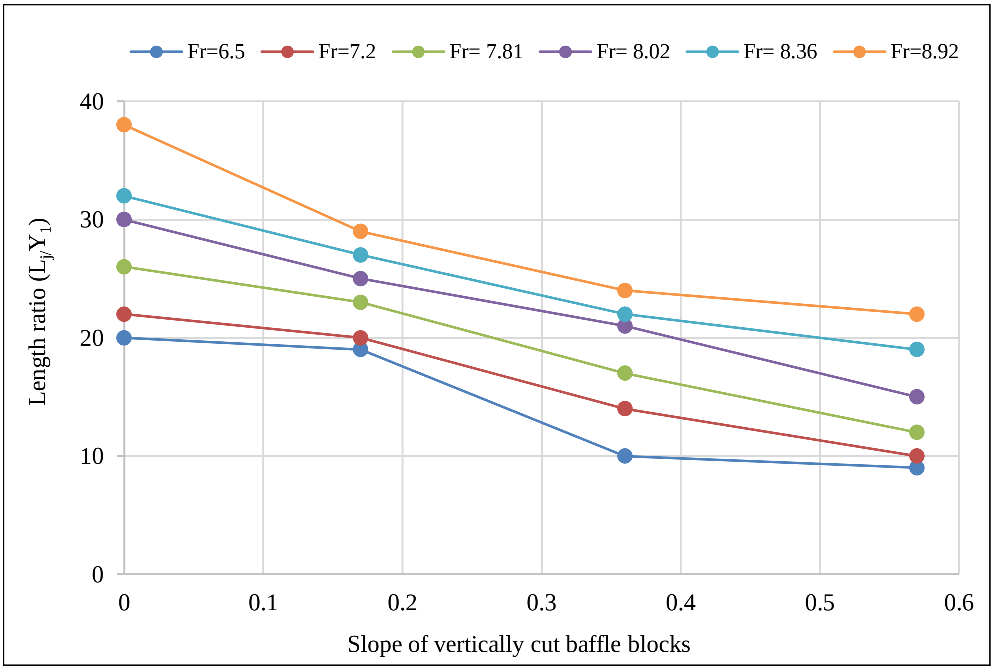

Figure 9. The relationship between slopes of the V-shaped baffle blocks, in a vertical position, and ratio of L_j/Y_1

For the semi-cylinder baffle blocks, Figure 10 shows the relationship between the blocks' slopes and the ratio of L_j/Y_1 at different F_r values (6.5-9.2). It can be noticed that the relationship is similar to that of the V-shape baffle blocks for all the studied F_r.

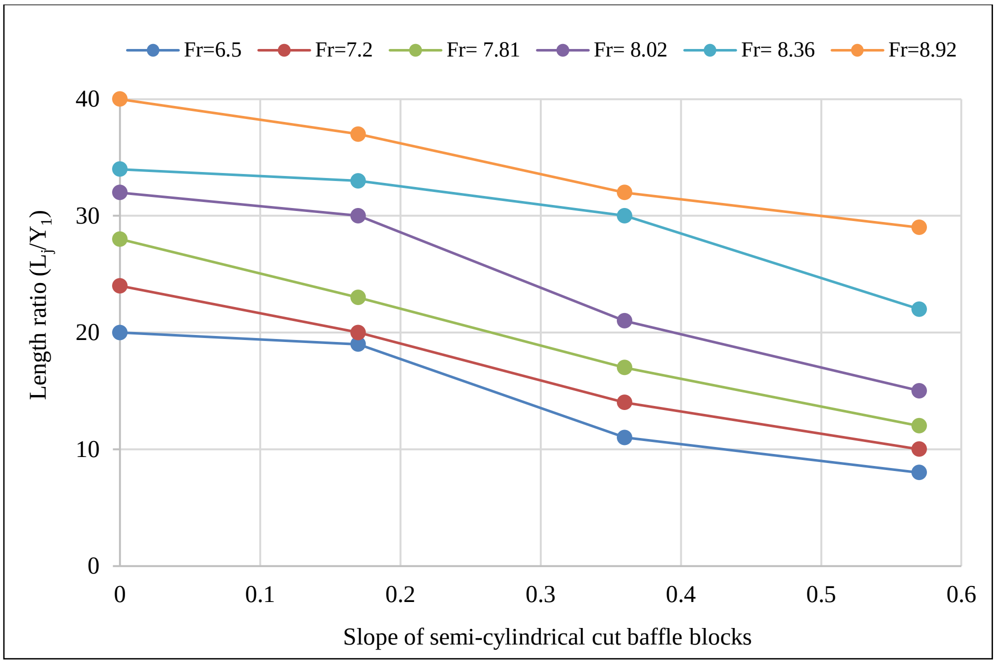

Figure 10. The relationship between slopes of the semi-cylinder baffle blocks and the ratio of L_j/Y_1

4.3. The Drag Force Applied on the Baffle Blocks

Figures 11 and 12 shows the relationship between the ratio of F_B/F_2, at different Fr values, and the slope of the V-shaped block at horizontal and vertical positions, respectively. These figures indicate a direct relationship between the ratio of F_B/F_2 and the slope of the V-shaped baffle blocks at both horizontal and vertical positions. For example, at horizontal position and F_r= 6.5, the ratio of F_B/F_2 increased from 43 to 82.6% as the slope increased from 10^0 to 30^0, respectively (Figure 11). Similarly, at vertical position and F_r = 6.5, the ratio of F_B/F_2 increased from 45.7 to 94.6% as the slope increased from 10 to 30^o, respectively (Figure 12).

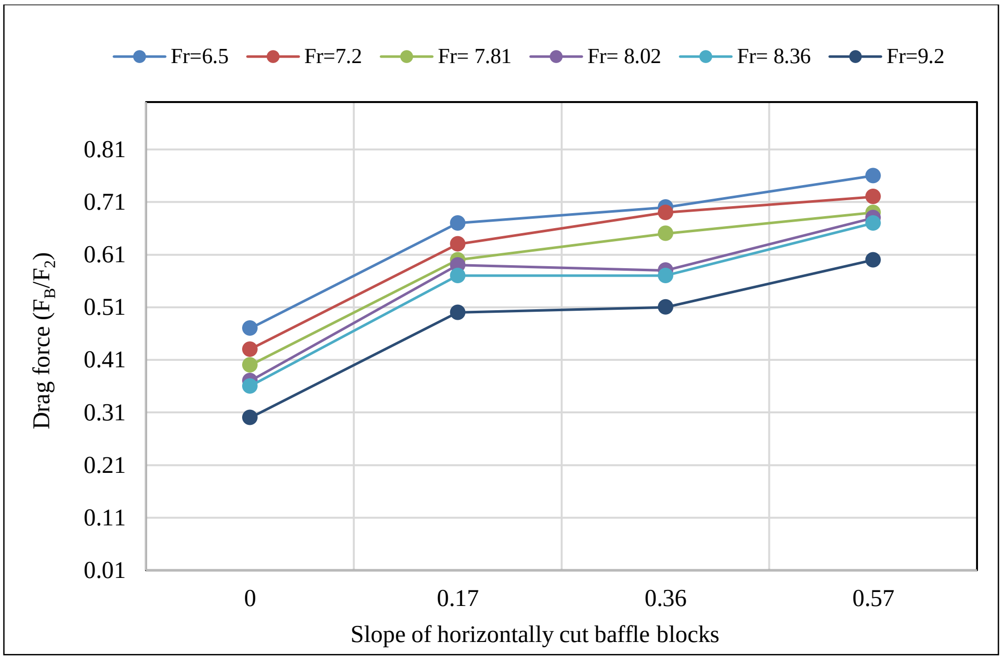

Figure 11. The relationship between slopes of the V-shaped baffle blocks in a horizontal position and the ratio of F_B/F_2

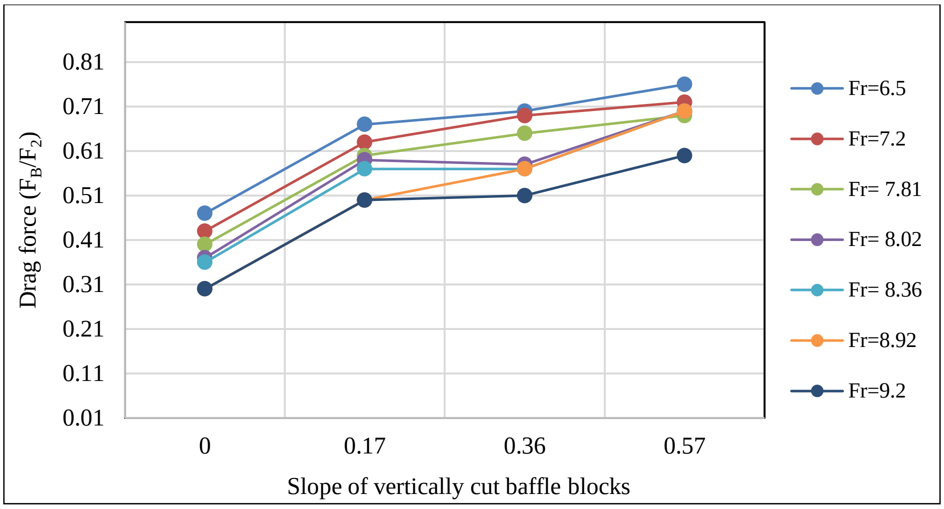

Figure 12. Slopes of the semi-cylinder baffle blocks, in a vertical position, vs the drag force (F_B/F_2)

Figure 13 shows the relationship between slopes of the semi-cylinder baffle blocks and the ratio of F_B/F_2 for Fr values ranging between 6.5 and 9.2. A direct relationship, for all F_r values, has been noticed between the slope of the baffle blocks and the ratio of F_B/F_2.

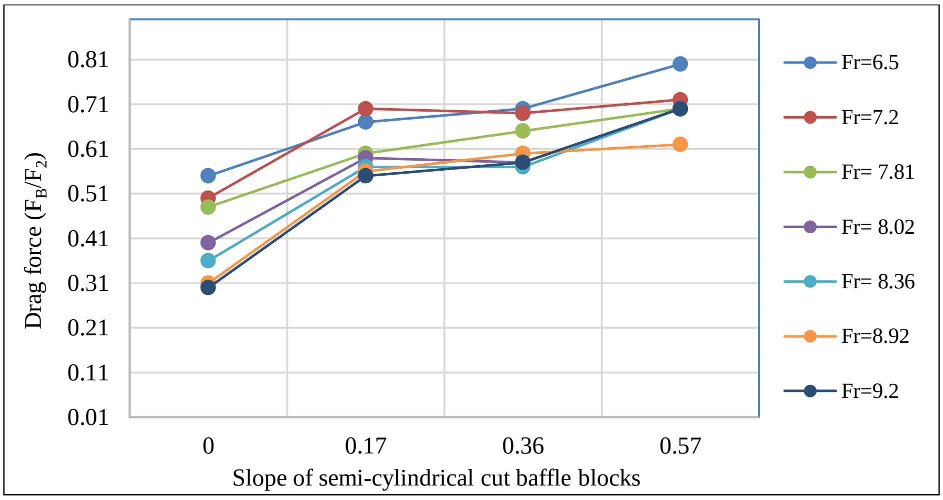

Figure 13. Slopes of the semi-cylinder baffle blocks, in a horizontal position, vs the drag force (F_B/F_2)

In addition, it can be noticed that the effect of the flow depth variations along the length of the stilling basins as shown in Figure 14. Finally, due to the recent development in the sensing technology [36, 37] and application of baffle plates in different water treatment facilities [38, 39], the authors recommend using sensing technologies to monitor the behaviour of drag force and water jumps, which will provide very useful information for future studies.

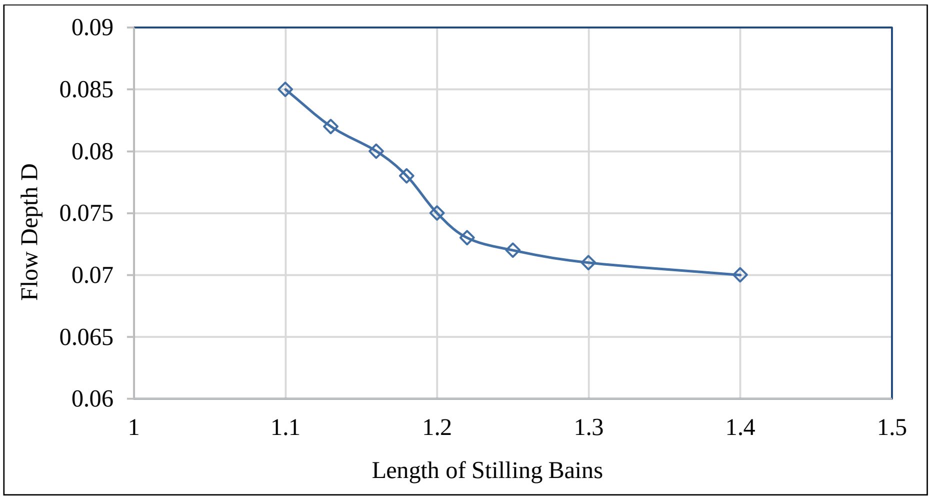

Figure 14. Variation of flow depth along stilling basins

5. Conclusion

With the change in the cutting angle of the baffle blocks in both horizontal and vertical locations, the amount of energy dissipation decreases with the frequency of Fr. However, this increase in the vertical position is more than it is in the horizontal position under the same experimental conditions. Ratio of length of hydraulic jump to the initial depth (L_j/Y_1) is inversely proportional to the cutting angle in both vertical and horizontal positions, and it is directly proportional to F_r value. Additionally, it has been found that the reduction ratio in hydraulic length in the vertical position is more than it is in the horizontal position under the same flow conditions. According the rules of energy conservation, the rate of force increasing should be proportionally to the rate of reductions of jump length. And Ratio of applied drag force on the baffle blocks (F_B/F_2) increases with the increase of cutting angle and the initial F_r value. The hydraulic performance and applied drag force on the semi-cylinder baffle blocks are similar to that of the 30^o V-shaped ones under the same conditions. At the end, in this study drag coefficient values were identified in terms of the main Froude numbers for various baffle pieces. Results indicated that the drag coefficient values for the vertically cut blocks in the same flow conditions were smaller than the horizontally cut baffle blocks. However, the average values of the pressure exerted on the surface of the vertically cut baffle blocks were smaller than on other ones, making them better than others.

6. Conflicts of Interest

The authors declare no conflict of interest.

7. References

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