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Effect of Hollow Semi-Circular Baffles Arrangement on Local Scour Downstream Hydraulic Structures

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KEYWORDS:
Circular Baffles, Local Scour, Hydraulic Structures, Experimental Work.

***Abstract*—The purpose of this research is to examine the effect of using hollow semi-circular baffles, on scour hole dimensions downstream hydraulic heading-up structures. Different flow conditions and various geometrical parameters are considered. Fifty-four experiments are carried out under live bed scour conditions. The experiments consist of six sets, each one forced to the same flow conditions, but represents a different suggested geometrical arrangement of the baffles. Results showed that the best position of the baffle is located at the first one- third of the floor length with relative diameter equals to 0.74 to the initial water depth (gate opening). This position causes reduction equal to about 50% for the maximum depth of scour, with respective to the case of flat floor (no baffles). While the extended length of the scour is reduced to about 31%. On the other hand, the second baffles position, at the two-thirds of the floor length reduces only the relative scour length to about 57%. Based on the experimental results, empirical dimensionless relationships are developed for both maximum scour length and depth.**

I. INTRODUCTION

SCOUR is the operation of moving materials from a stream bed, by the kinetic erosive waterpower that is generated from transferring the potential energy upstream any heading-up structure to a kinetic energy at its downstream. Regulators, barrages, weirs, small dams, and spillways are examples of these structures. Heading-up structures are badly affected because of the created scour at their downstream toes. Protection against scour is an inevitable design step to keep the heading-up structure safe as possible. Different devices and philosophies are traditionally used to dissipate the erosive kinetic water energy downstream the heading-up hydraulic structures, e.g., by using a hydraulic jump, baffles, floor blocks, floor steps, sills and dropped basins.

Baffles are widely used because they have performed effectively as an energy dissipators, besides their advantage in stabilizing the formation of the hydraulic jump within the downstream floor. Different shapes, arrangements and dimensions of baffle blocks were suggested and studied in the literature. Abdallah [1], studied the effectiveness of end sill height and its shape on the scour hole dimensions downstream a solid apron. He found that, the sill height has a good effectiveness on minimizing the scour hole dimensions than its shape. Nashat [2], studied experimentally the sill compatible location with the floor to control scour downstream of heading-up structure.

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El-Masry and Sarhan [3], studied experimentally effect of using single line of angle baffles in four positions, for each position they changed the baffle height to study the characteristics of the scour. They concluded that, the effect of changing the height of baffles has small influence on the scour hole depth, in comparison with increasing the ratio between the baffle's location and the floor length. The most pronounced reduction of the scour depth was found when the baffle was located near to middle of the floor.

El-Gamal [4], investigated the effect of three lines of angled baffles on scour downstream hydraulic structures taking various heights and positions of the baffles, under different flow conditions. He concluded that, minimum dimensions of scour hole were obtained, for all studied positions of baffle lines and for range of ratio between angle baffles height to angle arm length equal to 0.66 and 1.0. The minimum values of scour hole dimensions occur at baffles position located at one third of floor length. Abdel Haleem [5], studied the effect of semi-circular baffle blocks on local scour downstream Fayoum type weir, taking into consideration different heights and arrangements of baffle blocks with different flow conditions. He concluded that, all the proposed baffle block arrangements, decrease both maximum depth and length of the scour hole. Contrary to, El-Masry and Sarhan [3], the effect of baffle block heights on minimizing the scouring proprieties had more significance than the baffle block positions.

El_nikhely [6], studied experimentally the effect of using single line of curved vertical sill with various diameters and locations on the scour hole parameters downstream spillway. She indicated that, the best location of curved sill located at the first one third of floor length. Aydin and Ulu [7], studied the effects of different shaped baffle blocks on dissipation of energy and the downstream scour of a regulator. They concluded that, the baffle blocks of all types were strictly reduced the downstream scouring, and the most effective baffle shape was a triangular shape with vertical upstream face, which was also the best energy dissipator among all used shapes due to its generation of hydraulic jump at the downstream.

Shahsavari, et al. [8], studied the effect of V-shaped blocks positions and their heights for different Froude numbers, on local scour. Al-Mansori et al. [9], studied the performance of new design for seven baffle blocks in term of hydraulic jump length reduction and rate of energy dissipation. Additionally, the performance of these new baffle blocks had been compared to the performance of the standard types of the baffle blocks. The seven baffle blocks, V-shaped blocks and Semi-Cylinder blocks, arranged in vertical and horizontal positions. The results showed that, in comparison to the standard blocks, the suggested blocks dissipated the energy increased by 9.31% and the length of the hydraulic jump decreased by 38.6%.

Zare [10], and Pagliara [11, 12], evaluated the effect of adding baffles and end sills on energy dissipation, for flow over stepped spillways with sharp or round edges, and with an ogee intake. They found that, rock blocks can be used to improve energy dissipation on the ramp. Also, they discovered that baffle-edge chutes, as opposed to sill-edge chutes as well as circular and sharp-stepped spillways, achieved a higher energy dissipation rate. A flow energy dissipator of impact type is a chute construction with baffled blocks. A baffle block chute does not diminish velocity; instead, it stops flow acceleration, allowing a low-energy flow to reach the downstream.

Many different shapes of baffle block have been discussed and studied by Peterka [13], El-Masry [14]. Vischer and Hager [15], described the baffle block parameters and recommended the following conclusions:

- The first row of the baffle blocks has more effect in minimizing the scour dimensions than the effect of adding a second row.
- The upstream face of the baffle block should be perpendicular to the flow direction.

Over time researchers made a global study for local scour downstream hydraulic structures, and they established that, it is necessary to control the local scour depth; to ensure safety of these structures. Despite of the numerous studies, the problem of scour has not been resolved effectively so far.

Through the current research, with consideration to the recommendations of previous investigations, a suggested semi-circular baffles are considered to be perpendicular to the flow. The suggested baffles are easy to be applied as a pre-cast unit to the existing floors, of hydraulic structures, to enhance the scour parameters. The semi-circular baffles adopted here, due to the expected dissipation in water energy from collision reversed water at the circular baffles with the remaining part flowing in the downstream direction from the sluice gate.

Dimensional Analysis

The dimensional analysis is used to realize relationship between the different variables affecting the scour parameters. In this study, the maximum depth of scour hole, d_{sm}, and the maximum length of scour hole L_{sm}, are the main studied parameters for the scour hole. They can be expressed as a function of the remaining variables as follows.

$$d_{sm} \text{ or } L_{sm} = f\left(B, L_f, L, D, t, y_1, y_2, D_{50}, Q, \rho, \mu, g, Ts, \sigma_D\right) \quad (1)$$

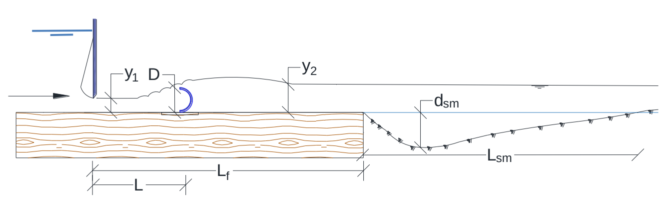

Figure (1): Layout of the single line (semi-circular baffles).

where, B is the flume width (L), L_f is the downstream apron length (L), L is the distance from the sluice gate to the baffle (L), D is the baffle diameter (L), t is the baffle thickness (L), y_1 is depth of water at the sluice gate (L), y_2 is the tail water depth (L), D_{50} is the median diameter of the bed particles (L), Q is the discharge under the sluice gate (L^3/T), ρ is density of the liquid (M/L^3), μ is dynamic viscosity of the liquid ($ML^{1-}T^{-1}$), g is gravity acceleration (L/T^2), Ts is required time to stable scour hole (T), and σ_D standard deviation of erodible particles diameters (L).

In the present study, the following parameters are kept constants as: mean diameter of the soil particles (d_{50} = 0.55 mm), the experiment time run (Ts =2 hrs.), the channel width (B = 40 cm), the floor length (L_f = 110 cm), standard deviation of the soil particles (σ_d=2.45), water density (ρ = 1000 kg/m^3), water viscosity ($\mu = 8.91*10^{-4}$ kg/ (m.s)), and the baffle thickness (t = 2.3mm). Thus, eq. (1) can be simplified to:

$$d_{sm} \text{ or } L_{sm} = f(L, D, Q, y_1, y_2) \tag{2}$$

It must be noticed that, the whole discharge (Q) can be represented as discharge per unit width (q = Q/B) or by the velocity (V = q/y), and the parameter (L) has a variable ratio from the constant parameter (L_f). Applying the Buckingham theorem on the variables in eq. (2), it can be concluded the following two dimensionless relationships:

$$\frac{d_{sm}}{y_2} = f(\frac{L}{Lf}, \frac{y_1}{y_2}, \frac{D}{y_2}, Fr_2) \tag{3}$$

$$\frac{L_{sm}}{y_2} = f(\frac{L}{Lf}, \frac{y_1}{y_2}, \frac{D}{y_2}, Fr_2) \tag{4}$$

where; $Fr_2 = V_2/\sqrt{gy_2}$ is Froude number at tail water depth y_2, and V_2 is the velocity (L/T).

II. EXPERIMENTAL WORK

A. Experimental Setup

The experiments are carried out in the irrigation and hydraulic laboratory at the faculty of Engineering, Mansoura University. A recirculating metal flume with dimensions 12 m long and 40 cm depth, was used to conduct the work. The flume width is 120 cm, but a constructed thinner wooden channel with only 40 cm width is used in the experiments. A streamlined lip sluice gate supplemented with a vertical measure are used to control the flow upstream the channel. A centrifugal pump is used to recirculate the water from the tail tank passing within a ground sump to the head tank. Flow control valve is used to assure the pre-specified discharge rates. The tail water level can be adjusted by a tail gate. Wooden floor is extended downstream the sluice gate for 110 cm with constant thickness equals to 20 cm. Then, an erodible sand bed with 20 cm of depth and longitudinal extension for 2 m, and with cross section has Perspex side walls, is used to study the proposed scour hole parameters. The remaining of the channel has constant depth of the erodible bed equal to 5 cm. A digital point gauge mounted on a movable measuring carriage, is used to detect the scour hole, see Photo (1).

B. Experimental Procedure

The erodible top surface is leveled horizontally as the same level of the wooden apron, for the whole channel. Then, the pump is started, and the inlet valve is opened gradually to fill the channel to a prespecified tail water depth, without any visible disturbance to the erodible bed. When the desired discharge is adjusted, and the flow started to pass within the sluice opening, the scour process is initiated. All experiments are stopped after 2 hours of running, assuming a live bed condition for the scour hole profile.

Photo (1): The experimental flume.

C. Experimental Scheme

The experimental work in this research was performed on six sets. Each of the experimental sets were restricted to the same nine flow conditions as:

1. Three discharge rates equal to 10.867, 13.694, and 16.731 Lit/sec, with corresponding gate opening equal to 3.5, 4.0, and 4.6 cm respectively.
2. For each discharge and a corresponding gate openings three different tail water depths were adjusted by the tail gate as: (y_2 = 7.8, 7.0 and 6.3 cm with corresponding Froud numbers F_{r2} = 0.4, 0.47 and 0.55) for gate opening y_1 = 3.5 cm; (y_2 = 8.6, 7.8 and 7.0 cm with F_{r2} = 0.43, 0.5 and 0.59) for y_1 = 4.0 cm; (y_2 = 9.4, 8.6 and 7.8 cm with F_{r2} = 0.46, 0.53 and 0.61) for y_1 = 4.6 cm. The resulted nine flow conditions are used repeatedly for all sets of experiments.

The six experimental sets are the following:

1) Flat floor without any baffles to be used as a reference, see figure (2). Responses of different baffle arrangements will be evaluated by comparing its results with the case of no baffle.
2) Three experimental sets represented three different locations of one single baffle (L/L_f =1/3, or 2/3, or 1). For all the previous four sets the used baffles diameters were restricted to 2.6 cm, see figure (3).
3) Two experimental sets with full/three rows of baffles at L/L_f = 1/3, 2/3, and 1 respectively, and the first set has a fixed baffles diameters equal to 2.6 cm. Whereas, the second set has varied baffles diameters equal to 2.1, 2.6, 3.4 cm, at L/L_f = 1/3, 2/3, and 1 respectively, See figure (4).

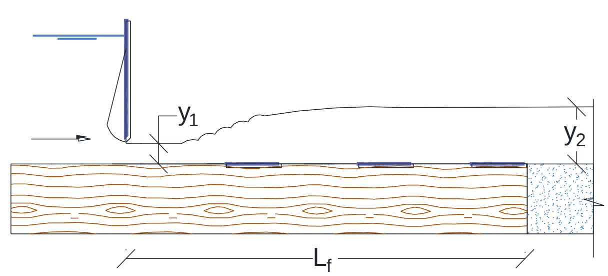

Figure (2): Definition sketch for the ordinary case (N.B).

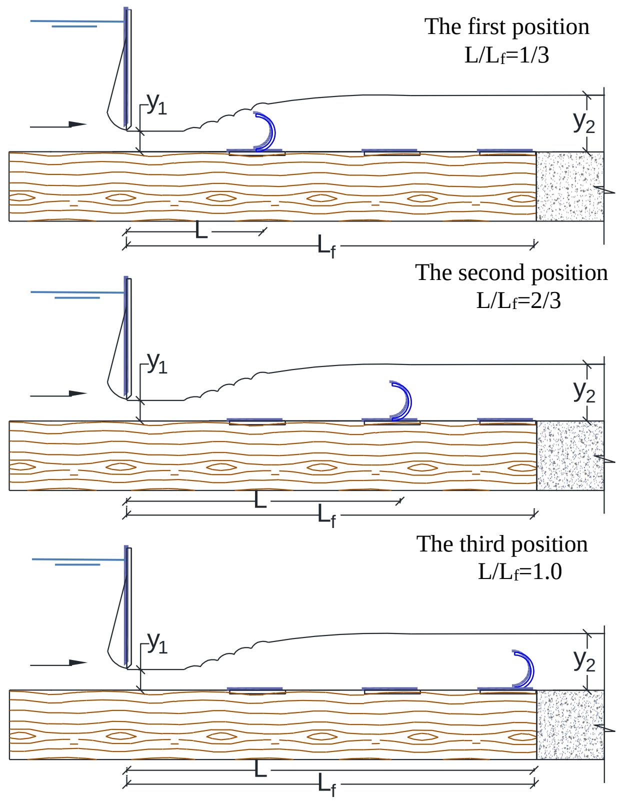

Figure (3): Definition sketches for the single case.

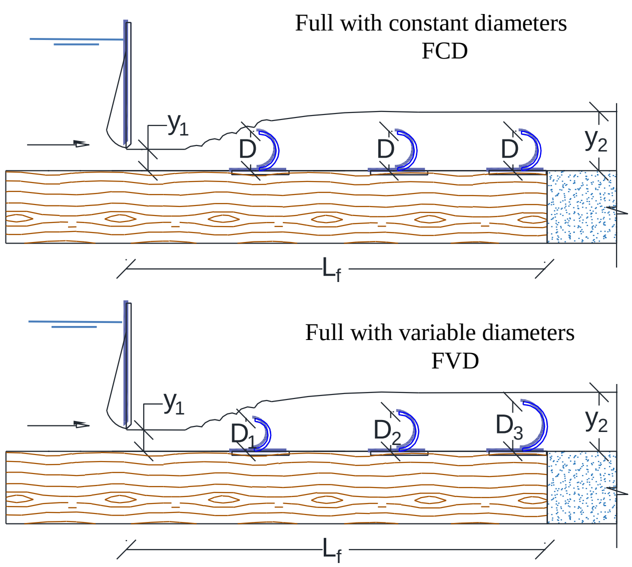

Figure (4): Definition sketches for the full floor cases.

III. RESULTS AND DISCUSSION

A. Effect of Downstream Froude Number On Scour for Case of No Baffles (N.B)

Froude number is one of the major factors affecting the scour characteristics. Figure (5) illustrates the recorded scour hole profiles those measured at the center of the flume for the case of flat floor with no baffles. From the figure it can be seen a realistic increase in the scour holes dimensions with increasing the downstream Froude number, Fr_2.

That logical trend validates to some extent the accuracy of the experiments carried out.

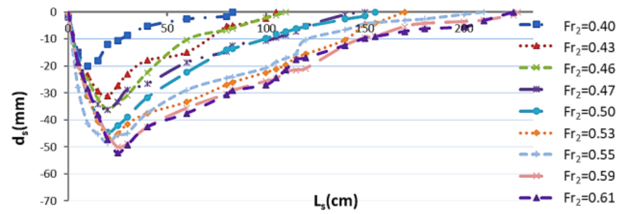

Figure (5): Scour profile at the flume center for ordinary case (N.B).

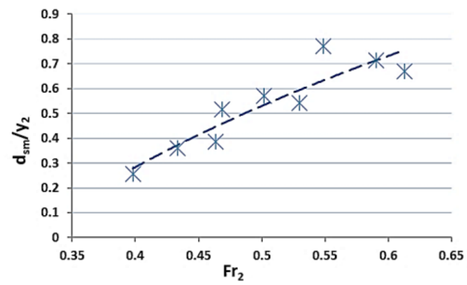

Figure (6-a): Relationship between maximum scour depth and Froude number for ordinary case (N.B).

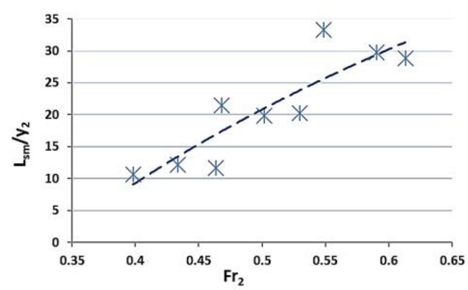

Figure (6-b): Relationship between maximum scour length and Froude number for ordinary case (N.B).

Figure (6) (a & b): Effect of the Froude number on scour depth and length for ordinary case flat floor (N.B).

Figures (6-a) and (6-b) show the relationship between Froude number and both local scour depth and length. From the figures it is observed that, increasing Fr_2 from 0.4 to 0.61 with ratio equals to 2.25, increases both d_{sm}/y_2, L_{sm}/y_2 by ratios 2, and 2.5 respectively. Thus, it can be concluded that the maximum dimensions of the scour holes are proportion linearly to the corresponding Froude numbers or more strictly to the downstream kinetic energy of the flow.

The above scour hole dimensions measured in case of no baffles are used as a reference to study the effect of different baffle arrangements under the same flow conditions.

B. Effect of Semi-Circular Baffle Arrangements on Scour

Figure (7) presents the relationship between the maximum relative scour depth d_{sm}/y_2 and downstream Froude numbers, Fr_2, for the nine flow conditions mentioned in the experimental scheme section. The experimental results are plotted for the five experimental sets, representing the different baffle arrangements.

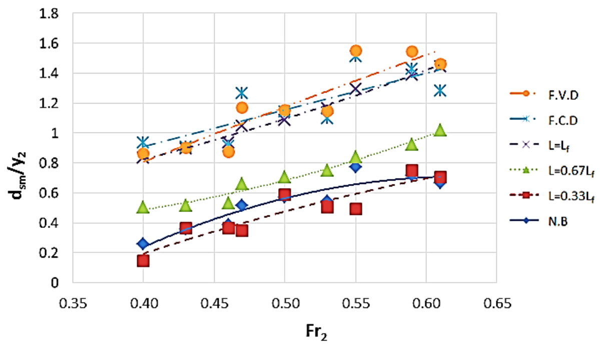

Figure (7): Relationship between (d_{sm}/y_2) and Froude number for different semi-circular baffle locations and D/y_1 from 0.57 to 0.74.

From figure (7), it can be concluded the following:

1. For all the studied experimental cases, the dimensional parameter d_{sm}/y_2 increases nearly linearly with increasing the downstream Froud number, Fr_2,
2. The maximum scour depth is decreased, with respect to the case of no baffles, only if the single semi-circular baffle is used at the first one third of the downstream apron $L/L_f = 1/3$, and for Froude numbers, $Fr_2 \leq 0.55$,
3. All results of the remaining sets of baffles arrangements show a worst deeper scour depth than the reference one, i.e., corresponding to the no baffles flat floor case,
4. The maximum scour depth of a single baffle goes deeper when that baffle moves downstream away from the first one third of the apron,
5. Using three rows of baffles instead of one increases the maximum scour depths.

Figure (8) illustrates the effectiveness of different semi-circular baffles arrangements on maximum relative scour depths (d_{sm}/y_2) for the three different gate openings (y_1 = 3.5, 4.0, and 4.6 cm). In the figure, the dimensionless ratio D/y_1 is calculated considering constant diameter for the semi-circular baffles equal to (D = 2.6 cm), even for the experimental set of full variable baffles diameters. The figure assures the same points concluded in the preceding paragraph.

Figure (9) represents the variation of relative maximum scour depths for the suggested semi-circular baffle arrangements, with respect to the results of flat floor without baffles. The relative maximum scour depth increased till 250% in case of using three baffles rows for full floor arrangement. The semi-circular baffle causes an improvement decrease in the maximum scour depth only in case of using one single baffle at the one third of the downstream apron, with percentage of reduction reaches to 49.75%.

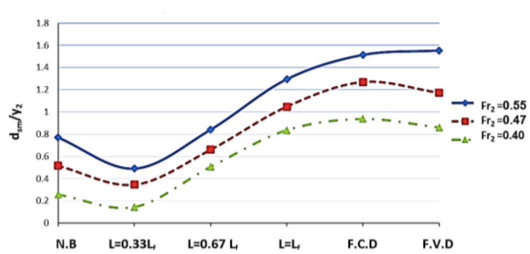

Figure (8-a) for D/y_1 =0.74

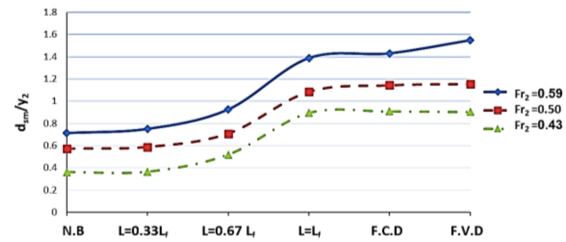

Figure (8-b) for D/y_1 =0.65

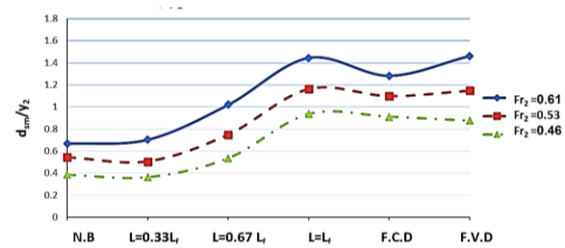

Figure (8-c) for D/y_1 =0.57

Figure (8): Impact of semi-circular baffle arrangements on maximum relative scour depth (d_{sm}/y_2), for different values of D/y_1.

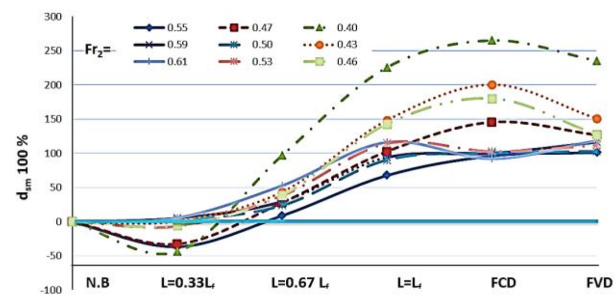

Figure (9): Impact of semi-circular baffle arrangements on relative maximum scour depths.

Figure (10) presents the relationship between maximum relative scour length L_{sm}/y_2 and downstream Froude number, Fr_2, for relative circular baffle diameters (D/y_1) equal to (0.57,0.65,0.74), were y_1 = 3.5, 4.0, and 4.6 cm; and D =2.6 cm. The experimental results are plotted for five cases and compared with the case of flat floor without baffles.

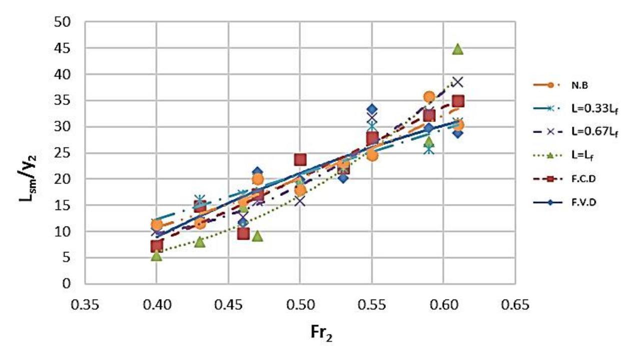

Figure (10): Relationship between (L_{sm}/y_2) and Froude number for different semi-circular baffle locations and D/y_1 from 0.57 to 0.74.

Figure (10) shows that, the circular baffle position is an influencing factor in minimizing relative longitudinal scour length, L_{sm}/y_1. In general, the increase in the downstream Froud number, Fr_2, increase the scour lengths L_{sm}/y_1. Irregular behavior for the different baffle arrangements can be noticed. Maximum reduction of L_{sm}/y_1 is observed for case of using single baffle located at L/L_f =2/3, and for $Fr_2 \leq 0.5$. But the maximum increase in L_{sm}/y_1 is also noticed at the same baffle arrangement, L/L_f =2/3, for higher value of Froude number.

Figure (11) shows the effectiveness of semi-circular baffle arrangements on maximum relative scour length (L_{sm}/y_2) for different values of D/y_1, where D is considered constant equals 2.6 cm and y_1 = 3.5, 4.0, 4.6 cm, respectively. From the figure, for D/y_1 = 0.74 and 0.65, the maximum reduction in the relative scour lengths, L_{sm}/y_1, can be observed at L/L_f =2/3, with maximum reduction ratio equals to 57.3%. But, as D/y_1 decreases to 0.57, the L_{sm}/y_1 results show an increase with respect to the corresponding reference results. That behavior may be explained by the expected occurrence of the hydraulic jump nearer to the sluice gate for lower values of y_1. For D/y_1 = 0.74, and L/L_f = 1/3 a noticeable reduction in L_{sm}/y_1 can be seen with a maximum reduction ratio equals to 31.3%. Consequently, using semi-circular baffles is encouraged only in case of using one single baffle at L/L_f =1/3 and for D/y_1 = 0.74, whereas both L_{sm}/y_1, and d_{sm}/y_1 are decreased significantly, see figures (8-a and 11-a).

From figure (11-a), at D/y_1 =0.74, all the suggested baffle arrangements showed a reduction in L_{sm}/y_1 for Fr_2 = 0.55, and 0.47. While form figure (11-c) all the baffle arrangements have an increase in L_{sm}/y_1, for Fr_2 = 0.61 and 0.53. The remaining Froude numbers, Fr_2, have irregular trend for different baffle arrangements.

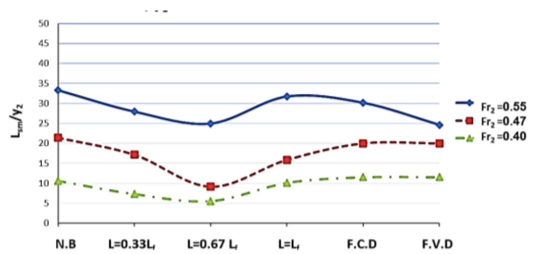

Figure (11-a) D/y_1 =0.74

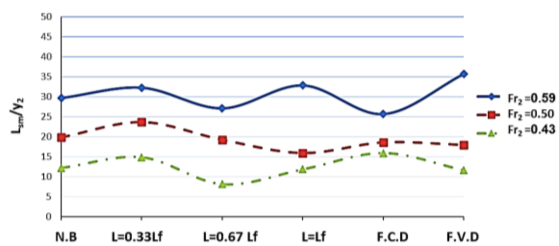

Figure (11-b) D/y_1 =0.65

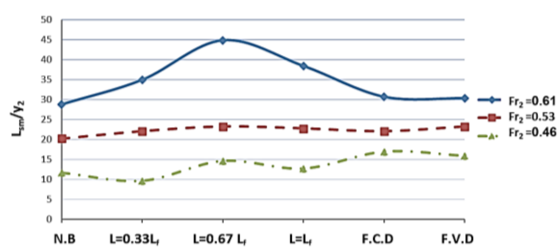

Figure (11-c) D/y_1 =0.57

Figure (11): Impact of circular baffle arrangements on maximum relative scour length (L_{sm}/y_2).

For the different suggested semi-circular baffle arrangements, figure (12) represents the variation of relative scour lengths, with respect to the case of no baffles case.

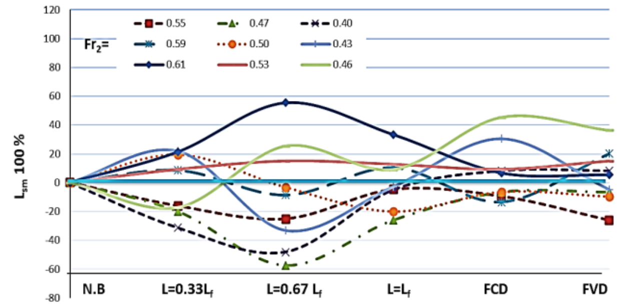

Figure (12): Impact of semi-circular baffle arrangements on maximum scour length.

From the figure it is clear that, there are irregular trends of different downstream Froude numbers, Fr_2, on relative scour lengths for different baffle arrangements.

Figures (13) through (15), illustrate the recorded actual scour hole profiles for all baffle arrangements in addition to the case of no baffle flat floor. The figures represent the three gate openings at D/y_1 = 0.74, 0.65, and 0.57, respectively. Scour profiles represent the scour dimensions at the center of the flume. The three cases I, II, and III represent on single baffle at L/L_f = 1/3, 2/3, and 1, respectively. While the case of F. F represents three rows of baffles at L/L_f = 1/3, 2/3, and 1.

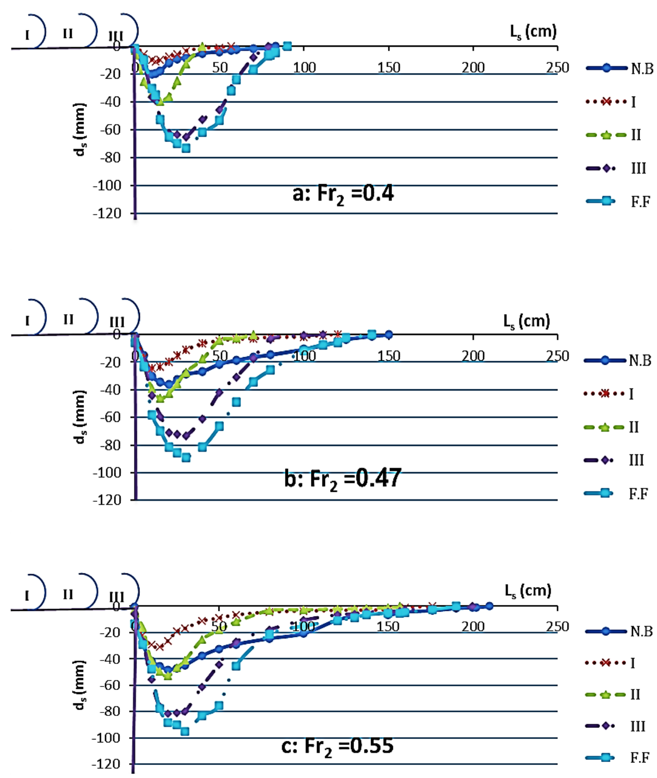

Figure (13): Scour hole profiles for (D/y_1) =0.74 and Fr_2 =0.4, 0.47 and 0.55.

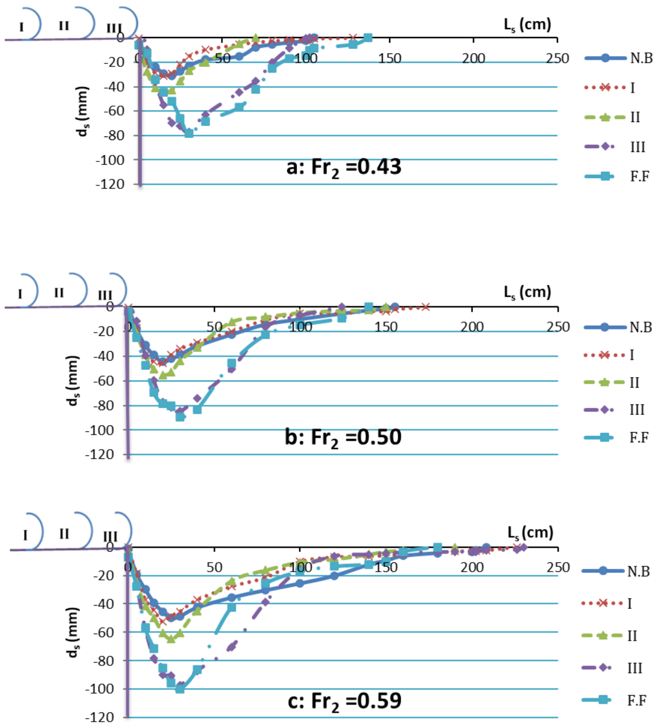

Figure (14): Scour hole profiles for $(D/y_1) = 0.65$ For Fr_2 =0.43, 0.50 and 0.59.

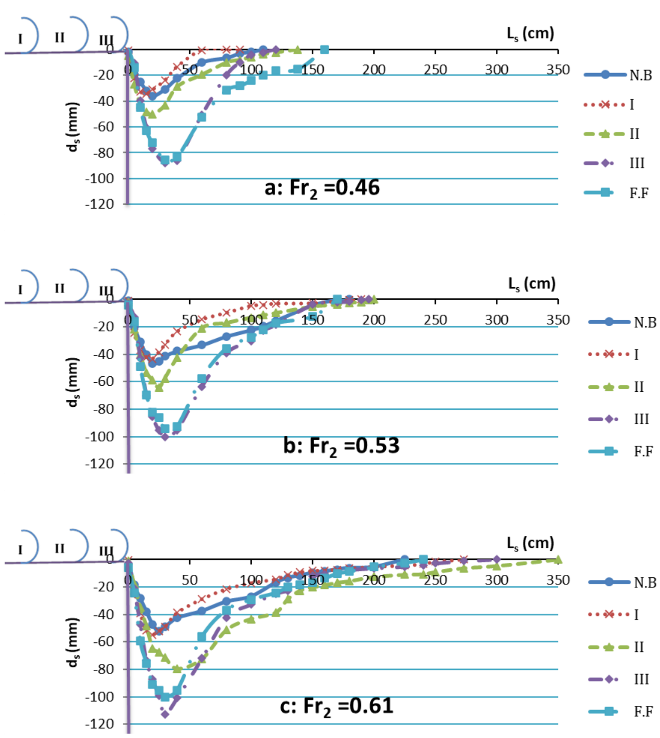

Figure (15): Scour hole profiles for (D/y_1) =0.57 For Fr_2 =0.46, 0.53 and 0.61.

The recorded scour hole profiles were measured at the center of the flume. From these figures, it became clear that for smaller values of Froude number the scouring activities were not appreciable, but for higher Froude numbers the effect is clearer and more appreciable, the scour depth increased with the increasing of Froude number.

From the conducted profiles, it was obvious that Froude number is an important factor in the scour process. Froude number has effects not only on the values of scour parameters but also on the rate of their increase. Analysis of the experimental results showed that, the increase of scour parameters rate was very large at first, then it began to decrease until it reached zero.

From figures (13) through (15), it became evident that, the maximum scour hole profile dimensions increased as the separated distance increased than L/Lf=0.33, comparing with the ordinary case (no baffles).

However, it is appreciable that, L/ Lf =0.33 gave the minimum scour hole dimensions with respect to all suggested arrangements at all including the case of no baffles.

Using full floor baffles with the considered dimensions increased scour hole dimensions' depth and length.

IV. DERIVATION OF MAXIMUM SCOUR PARAMETERS

It is worth to represent the main parameters affecting the design process, i.e., d_{sm}/y_1 and L_{sm}/y_1, in mathematical relations. The dimensionless parameters in Eqs. (3, 4) are used to generate a regression equation between both d_{sm}/y_1 and L_{sm}/y_1, and the remaining changeable dimensionless parameters. It must be kept in mind that these relations are restricted only for the range of the experimental scheme data adopted in the present research. The statistical package for the social sciences (SPSS) is used to find the desired regression equations with minimum errors between observed results and the calculated ones. As the determination coefficient approaches one, both the calculated results from the generated relations and the experimental ones are going to be identical.

Different forms of the desired relations are suggested, with different initial values for the unknown coefficients to catch the best tractable ones, for the experimental results. The following equations are concluded for the different baffle arrangements studied within the present work.

A. *Case of Flat Floor;*

$$\frac{d_{sm}}{y_2} = 21.2\left(\frac{y_1}{y_2}\right)^{5.4} - 222.5(fr_2)^{12.3} \qquad (5)$$

$$\frac{L_{sm}}{y_2} = 869.65\left(\frac{y_1}{y_2}\right)^{0.55} - 709.85(fr_2)^{0.28} \qquad (6)$$

B. *Case of Single Line of Circular Baffles;*

$$\frac{d_{sm}}{y_2} = 13.86(fr_2)^{0.32} - 15.32\left(\frac{y_1}{y_2}\right)^{0.32} + 2.43\left(\frac{D}{y_2}\right)^{0.30} + 0.63\left(\frac{L}{L_f}\right)^{2.36} \qquad (7)$$

$$\frac{L_{sm}}{y_2} = 3442.61\left(\frac{y_1}{y_2}\right)^{8.33} - 67389.06(fr_2)^{17.21} + 21.55\left(\frac{D}{y_2}\right)^{2.59} + 5.74\left(\frac{L}{L_f}\right)^{0.53} \qquad (8)$$

C. Case of Full Floor of Circular Baffles with Variable Diameters;

$$\frac{dsm}{y2} = 14.75\left(\frac{y_1}{y_2}\right)^{0.6} - 12.72(fr_2)^{0.26} + 3.46\left(\frac{D_1}{y_2}\right)^{0.38} - 4.28\left(\frac{D_2}{y_2}\right)^{1.8} + 6.95\left(\frac{D_3}{y_2}\right)^{3.78} \quad (9)$$

$$\frac{L_{sm}}{y_2} = 495.92\left(\frac{y_1}{y_2}\right)^{4.67} - 822.96(fr_2)^{9.11} + 83.26\left(\frac{D_1}{y_2}\right)^{0.107} - 78.5\left(\frac{D_2}{y_2}\right)^{0.15} - 6.29\left(\frac{D_3}{y_2}\right)^{-0.016} \quad (10)$$

For sake of explanation, the following example is used to explain how one can exploit the previously derived equations. Consider a flow discharge rate equal to 16.73 Lit/s from a sluice gate opening height equal to 4.6 cm. The corresponding flow velocity at the sluice gate, v_1, and the Froud number, Fr_1, will be 0.91 m/s, 1.35 respectively. If the downstream tail gate is adjusted for downstream water depth equal to 8.6 cm, the corresponding downstream velocity, v_2, and Froud number, Fr_2, are equal to 0.49 m/s and 0.53. From equations 5 and 6 the expected maximum scour depth and length in case of no baffle equal to 5.44 cm and 190.85 cm respectively, while, in case of using one single baffle sill at L/L_f = 1/3 and D =2.6 cm, from equations 7 and 8, the corresponding maximum scour depth and length are decrease to 4.44 cm and 186.88cm, illustrates the calculated and observed values of d_{sm}/y_2 and L_{sm}/y_2. Both maximum scour depth and length are decreased by 18% and 2% respectively, in case of using one single sill at L/L_f =1/3.

Figures (16) through (18) show the correlation between the experimental relative maximum scour depths (d_{sm}/y_2) and the calculated ones using equations (5), (7) and (9) respectively, with a determination range between 0.9693 to 0.8964.

Figures (19) through (21) compare the experimental relative scour lengths (L_{sm} /y_2) and the calculated ones using equations (6), (8) and (10), respectively with a worst determination equal to 0.868.

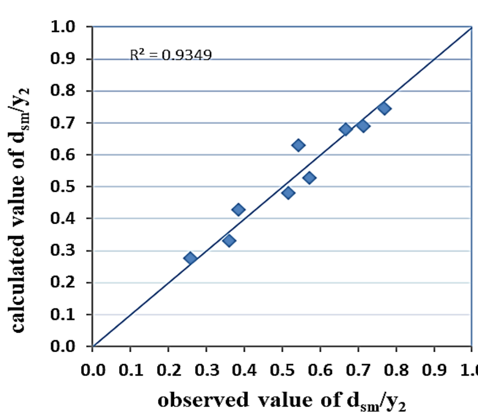

Figure (16) Comparison between calculated and observed values of d_{sm}/y_2 case of flat floor.

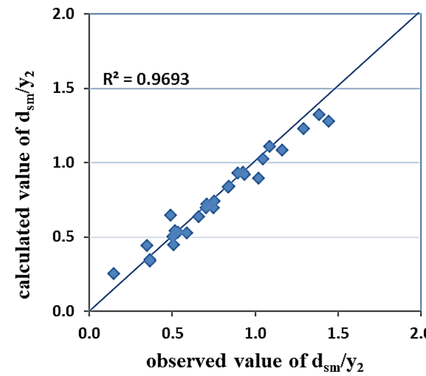

Figure (17) Comparison between calculated and observed values of d_{sm}/y_2 case of single line of baffles.

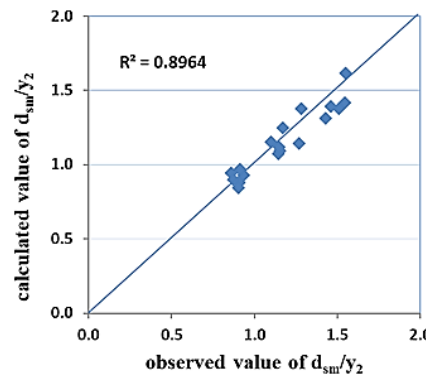

Figure (18) Comparison between calculated and observed values of d_{sm}/y_2 case of full floor baffles.

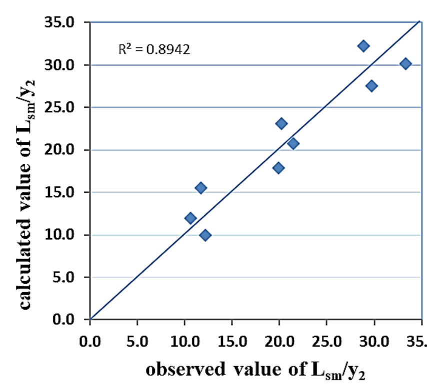

Figure (19) Comparison between calculated and observed values of L_{sm}/y_2 case of flat floor.

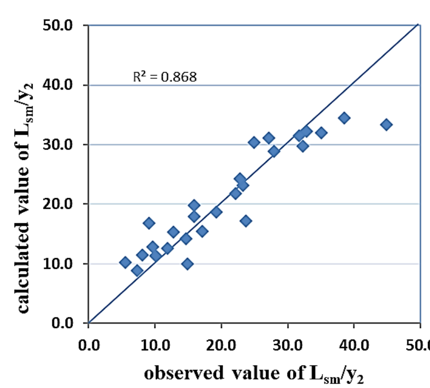

Figure (20) Comparison between calculated and observed values of L_{sm}/y_2 case of single line of baffles.

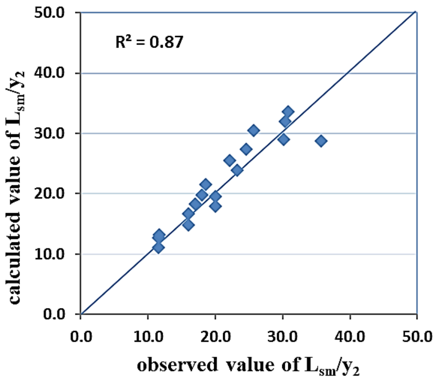

Figure (21) Comparison between calculated and observed values of L_{sm}/y_2 case of full floor baffles.

V. CONCLUSION

The experimental and statistical studies of local scour downstream of a sluice gate and subjected to different semi-circular baffles arrangements led to the following summaries and conclusions points:

- The semi-circular baffles can be utilized as an additional component to affect the scour hole dimensions downstream the sluice gate structure.
- The scour hole dimensions increase significantly with the increase in the downstream Froude number.
- Using full baffles floor, i.e., three rows of baffles, or one single baffle at the downstream floor edge increase the scour hole dimensions significantly.
- The best desired baffle arrangement is composed from one single row of baffle at the first one third downstream the sluice gate. That baffle arrangement is the only one which causes decrease in both maximum relative scour depth and length that reach 49.75% and 31.3% respectively.
- In case of using one single baffle the decrease trend in the relative maximum scour depth, is reflected to an increase as the baffle location moves away in the downstream direction. But the relative maximum scour length, is decreasing as the baffle location moves downstream till 0.67 of the floor length, then an irregular trend for the scour lengths can be noticed for the remaining baffle arrangements.
- Maximum reduction in maximum relative scour length, is produced from using one single baffle at 0.67 of the floor length, with a reduction ratio equal to 57.3%.
- In general, the cross section areas for the scour hole at the center line of the flume is less than the corresponding areas produced from the case of no baffle, when using one single baffle at 0.33 of the floor length.
- Different regression relations are created to simulate the experimental results of both maximum relative scour depth and length. Limited degree of errors can be observed between the experimental and the calculated results.

AUTHORS CONTRIBUTION

The following summarizes author statement outlining their individual contributions to the paper using the relevant roles:

1- *Rashed, R.*: Data collection and tools, data analysis and interpretation, investigation, methodology, Software, and drafting the article. Data analysis and interpretation.

2- *E l-Masry*, A. A: Conception and design of work, supervision, methodology, Supervision, Critical revision of the article, and final approval of the version to be published.

3- *Abdel-Gawad, H. A. A.*: Conception and design of work, data interpretation, supervision, and critical revision of the article.

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Title Arabic:

تاثير ترتيب الحواجز النصف دائريه على النحر خلف المنشآت الهيدروليكيه

Arabic Abstract:

يتسبب النحر في قاع المجرى المائي خلف المنشآت الهيدروليكية إلى تلفها وأحيانا إلى إنهيارها مما قد ينتج عنه العديد من الآثار السلبيه المدمرة .

الغرض الأساسي من هذا البحث هو دراسة تأثير الحواجز النصف دائرية في تقليل عمق النحر خلف المنشآت الهيدروليكية وذلك بدراسة المتغيرات الهندسية المختلفة (كقطر الحواجز الدائرية ومواقعها خلال فرشة المنشأ) وكذلك العوامل المختلفه لسريان المياه المختلفة داخل المجرى المائي.

أظهرت النتائج أن أفضل موقع للحواجز كان عند الثلث الأول من طول الفرشة مع قطر نسبي يساوي 0.74 من عمق المياه الأولي (فتحة البوابة). أشارت النتائج إلى أن الحواجز النصف دائرية المقترحة أدت إلى تقليل عملية النحر الأقصى حوالي نسبة 49.75٪ من العمق بدونها و 31.3٪ في طول النحر مقارنة بحالة الفرشة المسطحة. ولكن الوضع الثاني عند ثلثي الفرشه يقلل قيمه طول النحر بحوالي 57.3 % مقارنه بالوضع الاصلي بدون حواجز .