# *COMPARATIVE STUDY FOR SCOUR DOWNSTREAM FAYOUM TYPE WEIR USING SINGLE, DOUBLE ROWS AND FULLY SEMI-CIRCULAR BAFFLED BASINS*

*Fahmy Salah Abdelhaleem*

*Civil Engineering department, Benha faculty of engineering, Benha University, Egypt*
*E-mail: fahmyhri@gmail.com*

## ABSTRACT

Baffle blocks installed on stilling basins of control structures to minimize local scour downstream these structures. They are arranged in one or several rows orientated perpendicular to the direction of flow. The arrangement system of baffle blocks is based on model studies and they vary not only with the type of basin but also with the purpose of the investigation. Evaluate of the effectiveness of these arrangement can be achieved by comparing their performances. This paper presents a comparative analysis among the influence of single row; double rows, and fully baffled floor on scour downstream a Fayoum type weir based on own and other previously collected experimental data. Only, a semi-circular shape of baffle blocks was considered throughout this study. Several heights and positions of baffle piers were included at wide range of flow conditions. The parameters of the formed scour hole behind the weir were employed for the comparison among the different arrangements. Results indicated that the system of fully baffled floor was suitable for almost the tested flow conditions. The single and double rows of baffles are suitable for specific flow conditions within the tested range.

**Keywords:** Local scour, baffle blocks, stilling basins, physical model.

## 1 INTRODUCTION

Flow over or underneath hydraulic structures is a form of potential energy that is converted into kinetic energy behind these structures. This energy should be dissipated to avoid the occurrence of downstream scouring. Investigation of scour downstream control structures considers an important research field due to its frequent occurrence in practical engineering. Baffle blocks are installed on stilling basin to stabilize the formation of the jump and increase the turbulence and dissipate the energy.

Primarily, the literature in the field of baffle blocks was reviewed (i.e. **Edward (1959), Peterka (1978), El-Masry & Sarhan (2000), Vischer & Hager (1995), El-Masry (2001), Helal (2003)**

**Edward (1959)** highlighted the need of using baffle blocks on the stilling basin even if they are not required to stabilize the hydraulic jump. There are many types and shapes of baffles that were employed and served their intended purpose. Many types of baffles employed in existing structures were introduced by **Edward (1959)**. His experiments revealed that triangular blocks are satisfactory for the most stilling basin. Many different baffle block shapes were offered by **Peterka(1978)**. **Bhowmik (1975)** studied the effect of triangular baffle blocks with different inclination angles to the incoming flow on the scour characteristics, and he concluded that using baffle blocks normal to the flow direction gave good results. **Friedrich & Ulrich (1967)** investigated the effect of double rows of baffle blocks on a local scour downstream a weir. They used a flat basin without baffles for comparison purpose. It concluded that by the baffle blocks the scour parameters were decreased by more than 50%. **El-Masry & Sarhan (2000)** applied a single row of angle baffles on stilling basins to reduce the scour downstream a Fayoum type weir. In their work, angle baffle position was arranged in four positions (0.5, 0.6, 0.75, and 0.8 of solid floor length) and also four relative baffle heights were considered (i.e. 0.33, 0.66, 1.0, and 1.33 of tailwater depth). They believed that a single line of angle baffle block reduced the maximum scour parameters by values ranged from 50% to 90%. Moreover they indicated that, the most efficient case of single baffle block on scour depth for low Froude number when using relative baffle height of 1.33 and relative position of 0.5. **El-Masry (2001)** performed an extensive experimental work on scour downstream a Fayoum type weir using double rows of angle baffle blocks. **El-Masry's (2001)** data considers different heights and position of angle baffles with different flow conditions. He concluded that, using the system of double line of angle baffles reduced scour dimensions. Also, he recommended locating the baffle system adjacent to the weir body. **El-Gamal (2001)** conducted some experiments to investigate the effect of using three rows of angle baffles on scour downstream a Fayoum type weir. His Experiments also respected various heights and positions of the angle baffles with different flow conditions. He confirms the results of **El-Masry (2001)**. The effect of a fully angle baffled floor on the scour downstream a Fayoum type weir was experimentally investigated by **El-Masry (2001)**. He believed that the tested angle baffle arrangements reduced scour depth and length comparing with the case of flat floor. His results recommended that the arrangement of baffle that facing the flow with its arms reduced the scour hole dimensions more than the opposite ones. The system of fully baffled floor was suitable for tested flow conditions. **Helal (2003)** carried out experiments to study the effect of semi-circular baffle blocks on scour hole and hydraulic jump parameters downstream a Fayoum type weir. **Helal's (2003)** experiments considered the effect of baffle block heights, positions and two cases of arrangements of semi-circular baffle blocks (i.e. fully baffled floor and double rows baffle blocks). **Negm et al. (2009)** employed the curved hollowed deflector downstream of multi-vents regulator to examine its effect on the distribution of the flow within the stilling basin and on the reduction of the downstream scouring. They found that the optimal deflector width should be not more than 75% of the basin while the deflector should be fixed with a central angle of $90^{o}$. **Habibzadeh et al. (2012)** evaluated the performance of single row of baffle blocks in submerged hydraulic jumps. The flow in a submerged hydraulic jump with three-dimensional baffle blocks was experimentally examined by **Habibzadeh et al. (2014)**. They concluded that, for submerged hydraulic jumps the effect of the height, width, location, and number of rows of the blocks on energy dissipation efficiency was insignificant and baffle had significant effect on the flow regime. **Habibzadeh et al. (2016)** introduced the experimental measurements of the turbulence in submerged hydraulic jumps with baffle blocks. **Blasidell (1947)** showed that the floor blocks should occupy between 40 and 55% of the floor width and the most favorable conditions result when the baffles are placed perpendicular to the incoming flow. Moreover, the baffle blocks should be easy to construct, should be non-clogging and self-cleaning. **Abdelhaleem (2013)** performed an experimental work to reduce the scour downstream a Fayoum type weir employing single row of semi-circular baffle blocks with various baffle heights and positions under a wide range of flow conditions. **Bestawy (2013)** carried out a comparative study among different shapes baffle blocks (angle, trapezoidal, rectangular, curved and semi-circular baffle blocks). They arranged on the stilling basins on a single row. His results confirmed that the vertical semi-circular baffle has the most effect among other tested models for dissipating energy and minimizing downstream scouring.

**Vischer & Hager (1995)** discussed the baffle blocks parameters and recommended that the optimum blocks front face should be perpendicular to the approach flow, single row of blocks should be applied due to the effect of the second row is relatively smaller, and baffle blocks should not be utilized for approach velocity above 20 m/s.

This paper presents a comparative analysis of the tested baffles and flow conditions of the studies conducted by **Helal (2003)** and **Abdelhaleem (2013)**.The tested baffles shape is a semi-circular baffle and the system of installed baffle blocks downstream of the weir include single, double rows and fully baffled basins. The flow conditions are almost the same.

## 2 EXPERIMENTAL DATA

A definition sketch of a single row of baffle blocks at four different positions is shown in (Fig. 1). In this figure, b is the basin width, $D_o$ is the outer diameter of baffle, $D_s$ is the maximum scour depth, $H_b$ is the baffle's height, $L_b$ is the distance between baffles row and the toe of the weir, $L_f$ is the floor length, $L_s$ is the maximum scour length, $S$ is the clear distance between baffles in the normal direction of the flow, t is the thickness of baffle, $y_1$ is the initial water depth of a hydraulic jump and $Y$ is the tailwater depth. The experimental data were gathered from **Helal (2003)** and **Abdelhaleem (2013)**, Table 1.

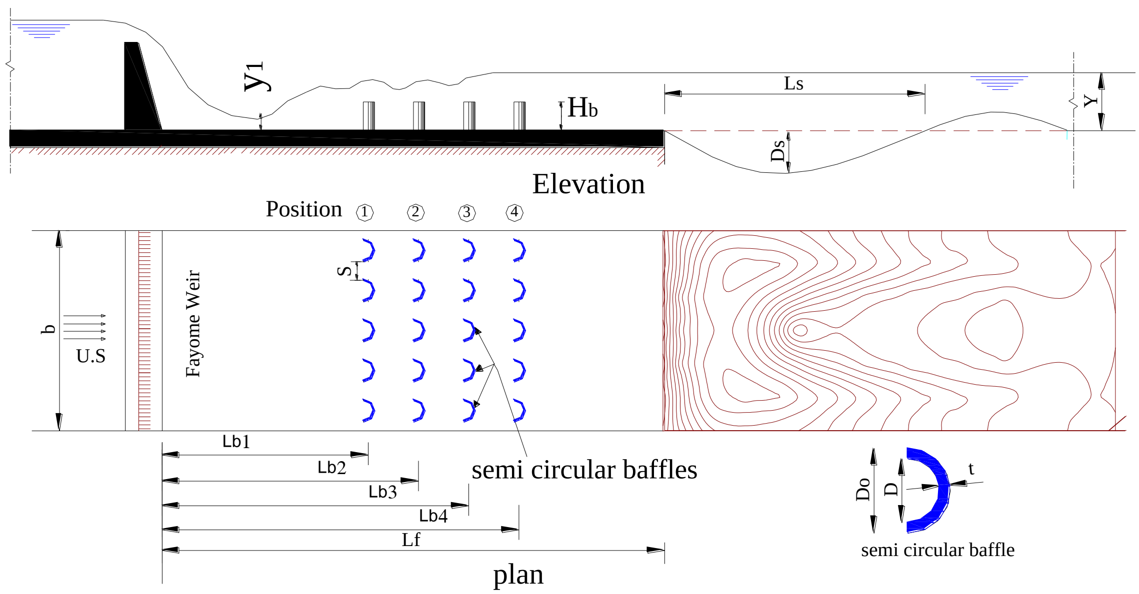


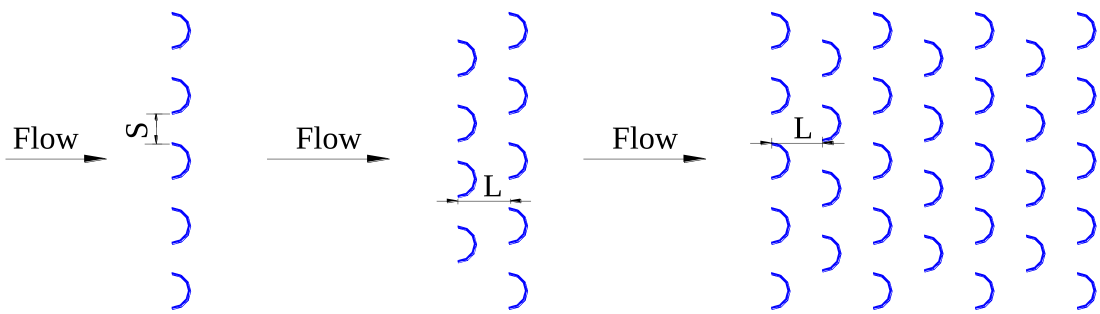

**Figure 1. A definition sketch of the single row of the semi-circular baffles at four positions and the associated parameters, Abdelhaleem (2013)**

**Table 1. Considered parameters for each study**

| **Parameters** | **Helal's (2003)** study | **Abdelhaleem's (2013)** study |
|---|---|---|
| Baffle's system | Double rows of baffles at different position and heights, and Fully baffled floor (7 rows), Fig. 2. | a single row of semi-circular baffle blocks with different height and different positions |
| Considered flume | Flume of (0.60 x 0.60 x 17.60 m) Perspex flume at Menoifa University | Flume of (0.60 x 0.60 x 20 m) Bricks with cement mortar at the Hydraulics Research Institute, HRI. |

| **Parameters** | **Helal's (2003)** study | **Abdelhaleem's (2013)** study |
| --- | --- | --- |
| Fayoum type weir | Contracted weir<br>Weir crest length = 50 cm<br>Weir height = 19.7 cm<br>Crest width = 5.0 cm<br>Slope = 1: 3 | Weir crest length = 60 cm<br>Weir height = 20.0 cm<br>Crest width = 4.0 cm<br>Slope = 1: 4 |
| Dimensions of the semi-circular baffles | $D_o$ = 6.0 cm<br>$D_{in}$ = 5.0 cm<br>t = 1.0 cm<br>S = 6.0 cm<br>L= 15 cm<br>$L_b$= 0.4, 0.5, 0.6 and 0.7 $L_f$<br>$H_b$= 0.33, 0.66, 1.0 and 1.33 $D_o$<br>The considered double lines of baffle blocks were arranged in staggered manner, the first line had a width of 40% of the stilling basin width, while the other had a width of 50%. | $D_o$ = 6.0 cm<br>$D_{in}$ = 5.4 cm<br>t = 0.6 cm<br>S = 5.0 cm<br>L = 0.0 (single row)<br>Baffle diameter considered according a sewer pipe of 2.5 inch.<br>$L_b$= 0.4, 0.5, 0.6 and 0.8 $L_f$<br>$H_b$= 0.334, 0.667, 1.0 and 1.33 $D_o$<br>according to **Edward (1959)** and **El-Masry & Sarhan (2000)**<br>The single line of baffle had a 50% open passageway across baffle vertical front as recommended **Pillai et al. (1989)** |
| Discharges | 21.4, 25.617 and 32.28 l/s | 20, 25 and 32 l/s |
| Tailwater depth for each discharge, Y | 10,10.5,11,<br>10,11.5,12.5,<br>11.3,12.5, and 13.5 cm | 10,10.5,11,<br>10,11.5,12.5,<br>11.3,12.5, and 13.5 cm |
| Initial water depth of a hydraulic jump, $y_1$ | 2.14, 1.98, 1.836,<br>2.88, 2.33, 2.04,<br>3.52, 3.038, and 2.7 cm | 2.14, 1.64, 1.75,<br>2.72, 3.74, 4.57,<br>2.58, 3.21 and 3.84 cm |
| Initial Froude for each discharge, $F_{r1}$ | 3.637, 4.58, 4.57,<br>2.74, 3.83, 4.60,<br>2.60, 3.24, and 3.87<br>Tail Froude number (at tailwater depth) was considered in analysis | 3.40, 5.07, 4.60,<br>2.72, 3.74, 4.57,<br>2.58, 3.21, and 3.84<br>Initial Froude number $F_{r1}$ was considered in analysis |
| The balance time | 2.0 hrs | 6.0 hrs |
| Measurements | Hydraulic jump parameters $y_1$ and $y_2$, maximum scour depth, length, and distance between | Maximum scour depth , length, and slopes of scour hole upstream and |

| **Parameters** | **Helal's (2003)** study | **Abdelhaleem's (2013)** study |
|---|---|---|
| | baffle and maximum scour depth, $L_m$. | downstream the apron. |




a- Single row, Abdelhaleem (2013)    b- Double rows, Helal (2003)    c- Fully baffled basin (7 rows), Helal (2003)

**Figure 2. Considered arrangement of semi-circular baffle blocks**

## 3 ANALYZING AND PRESENTING THE RESULTS

### 3.1 Identification of the main parameters

Variables were grouped into dimensionless terms to compare between the effect of single, double rows and fully semi-circular baffled floor on the scouring parameters, $D_s$ and $L_s$. The following functional relationship was obtained using the dimensional analysis:

$$\left( F_{r1}, \frac{D_s}{D_{sw}}, \frac{L_s}{L_{sw}}, \frac{H_b}{D_o}, \frac{L_b}{L_f} \right) \quad (1)$$

Where, $F_{r1}$is the initial Froude number at $y_1$, $D_s$ is the Maximum scour depth, $D_{sw}$ is the maximum scour depth without baffles, $L_f$ is the solid floor length, $L_s$ is the maximum scour length, and $L_{sw}$ is the maximum scour length in case of no baffles $L_b$ is the distance between baffles line and the toe of the weir, $H_b$ is the baffle's height and $D_o$ is the outer baffle's diameter.

### 3.2 Effect of semi-circular baffle blocks on scour hole depth

Results were grouped into dimensionless terms and the relationships were drawn to compare between the different arrangements of baffle system on the scouring dimensions.

Figs. from 3 to 6 illustrate the relation between $D_s/D_{sw}$ and $F_{r1}$ with respect to the considered values of baffle position, $L_b/L_f$ = 0.4, 0.5, 0.6 and 0.8, respectively. For each location, baffle heights are changed as $H_b$=0.334 and 1.33 $D_o$. For the considered flow conditions, using semi-circular baffle blocks reduce the depth of the scour hole compared to the depth in case of flat floor without baffles, $D_s/D_{sw}$< l. For all considered arrangements of baffle blocks with most tested values of $F_{r1}$, the case of fully baffled floor gave the smallest values of $D_s/D_{sw}$. Although, the case of double rows of baffle blocks should dissipate energy more than the single row, A single line of baffle blocks gave smaller values of $D_s/D_{sw}$ than double line baffle blocks except for $F_{r1}$> 4.0, and $H_b/D_o$ = 0.334. This effect is attributed to the arrangement of double rows of baffles in staggered manner leads to decrease the waterway and consequently produce more values of scour depth than those produced by the single row. It was observed that in all results, for higher values of $F_{r1}$ with all considered arrangements of baffle blocks there is relatively small influence of single, double rows, or fully semi circular baffled floor on the maximum scour depth except for the smallest values of baffle's height. When the single line baffle block installed at the end of roller length of the jump (i.e. $L_b/L_f$ = 0.4) and for $H_b/D_o$> 0.5, the single row produce the lowest values of $D_s/D_{sw}$.

According to Fig. 7, for the cases of fully baffled floor, the value of $D_s/D_{sw}$is decreased as the values of $H_b/D_o$ decreased. The same conclusion was observed for the single and the double line baffle blocks, except for $H_b/D_o$ = 1.33.

According to Fig. 8, for all considered arrangements of baffles with all tested values of $F_{r1}$, increasing of $L_b/L_f$ led to decrease the values of $D_s/D_{sw}$. whereas, it was clear that the influence of $L_b/L_f$ on $D_s/D_{sw}$ increased as $H_b/D_o$ increased. This emphasizes that using smaller values of $L_b/L_f$ reduced the value of maximum scour depth. The single line baffle gave more reduction in the scour depth than the double line especially for higher values of $H_b/D_o$. This may be attributed to the double line baffle blocks acted as a submerged weir when the double line baffle blocks used with higher values of baffle's heights.

For single line of baffle blocks, the value of $H_b/D_o$= 0.334 gave the higher values of $D_s/D_{sw}$ and the value of $H_b/D_o$= 1.33 gave the lower values of $D_s/D_{sw}$. The most efficient case of single baffle block arrangements for $F_{r1}$>3.5 when, using $H_b/D_o$= 1.33 and $L_b/L_f$ = 0.4, which produced reduction in scour depth ranged from 52.50% to 87.91%, these are agree well with the results of

**Edward (1959)** and **El-Masry & Sarhan (2000)**

The most efficient case of double line baffle block arrangements when using $H_b/D_o$ = 1.0 and $L_b/L_f$ = 0.4 produced reduction in scour depth ranges from 54% to 60% for $F_{r1}$< 3.5. But for $F_{r1}$> 3.5, using $H_b/D_o$ = 1.33 and $L_b/L_f$ = 0.5, produced reduction in scour depth ranges from 55% to 84%. The most efficient case of fully baffled floor is when installed with $H_b/D_o$ = 1.33, result reduction in scour depth ranged from 61% to 79%.

Reduction of scour hole depth due to using single line of baffle is close to double rows of baffles especially for lower values of $H_b/D_o$ and this is consistent with conclusion of **Vischer and Hager (1995).** Generally, the system of fully baffled floor was suitable for the most considered flow conditions. Single and double lines of baffles are suitable for specific conditions of flow.

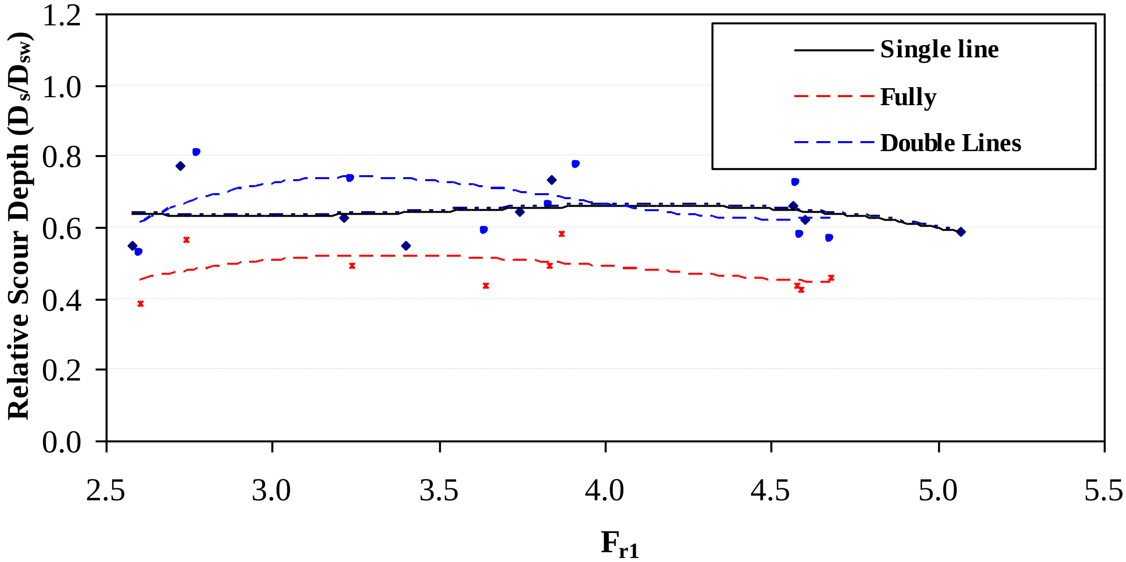



**Figure 3. Relationship between relative scour depth $D_s/D_{sw}$ and $F_{r1}$, ($L_b = 0.4\ L_f$ and $H_b/D_o = 0.334$)**

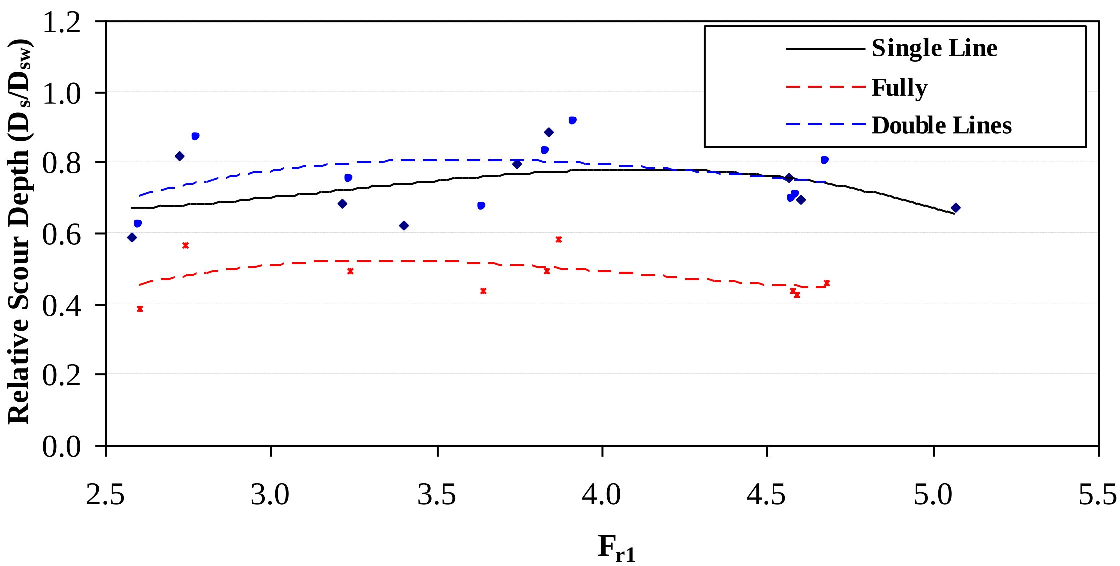



**Figure 4. Relationship between relative scour depth $D_s/D_{sw}$ and $F_{r1}$, ($L_b = 0.6\ L_f$ and $H_b/D_o = 0.334$)**

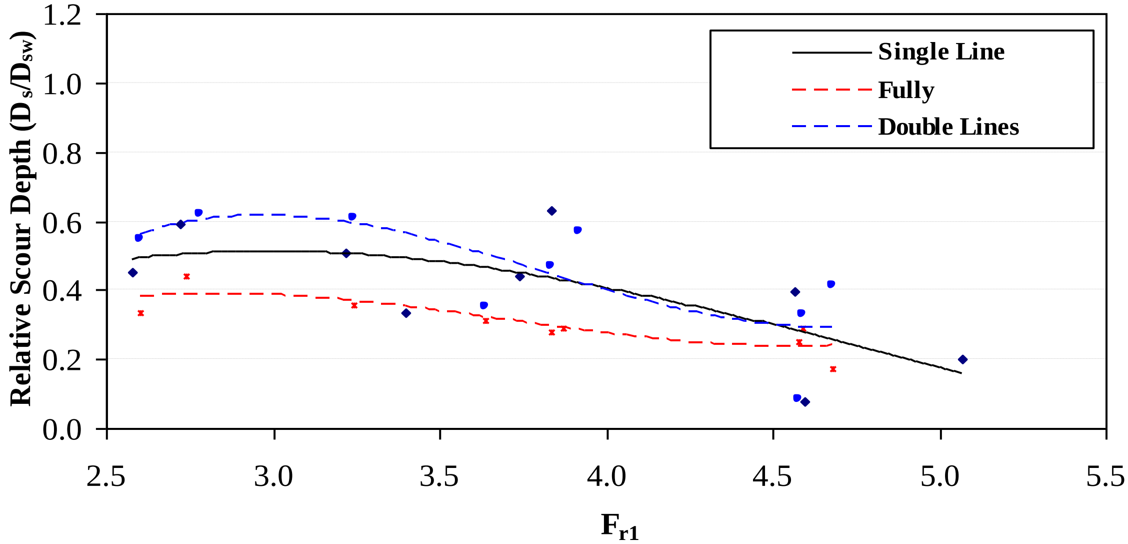



**Figure 5. Relationship between relative scour depth $D_s/D_{sw}$ and $F_{r1}$, ($L_b$ = 0.5 $L_f$ and $H_b/D_o$ = 1.33)**

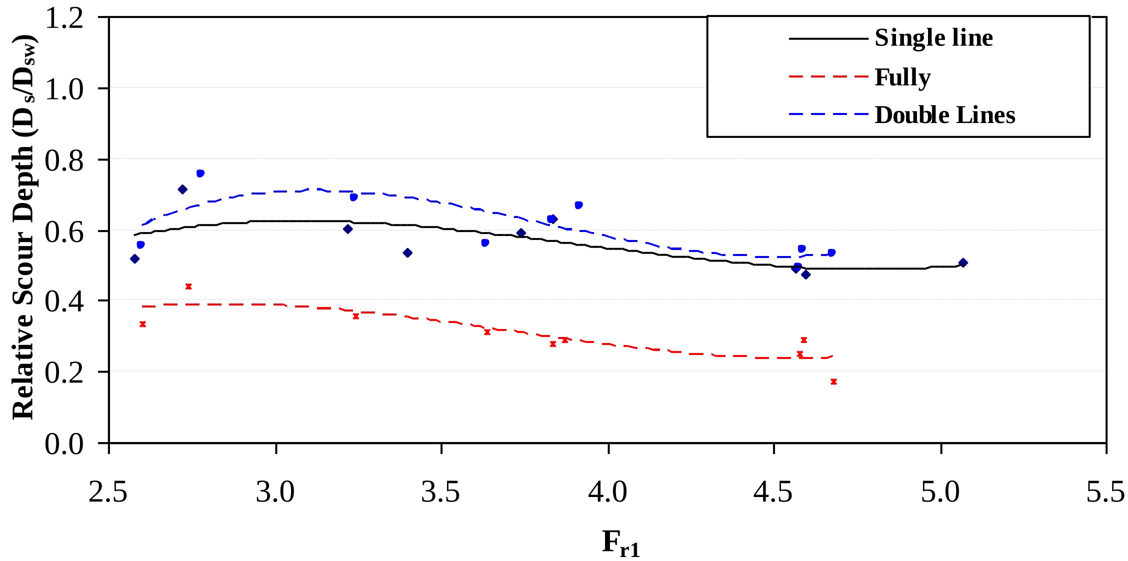



**Figure 6. Relationship between relative scour depth $D_s/D_{sw}$ and $F_{r1}$, ($L_b$ = 0.8 $L_f$ and $H_b/D_o$ = 1.33)**

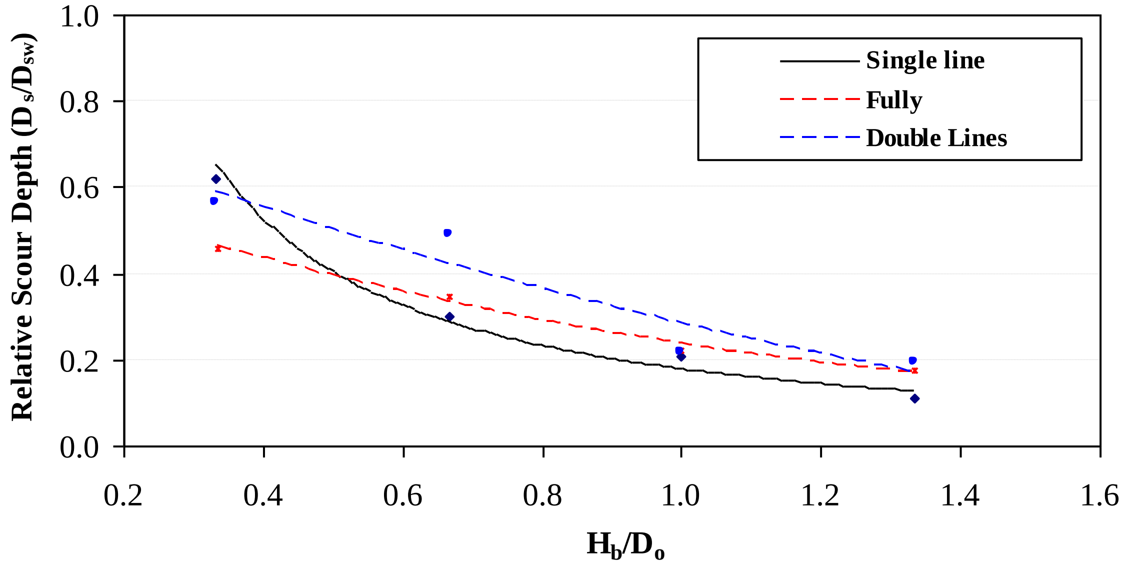



**Figure 7. Relationship between relative scour depth $D_s/D_{sw}$ and $H_b/D_o$, ($F_{r1}$= 4.60 and $L_b$ = 0.4 $L_f$)**

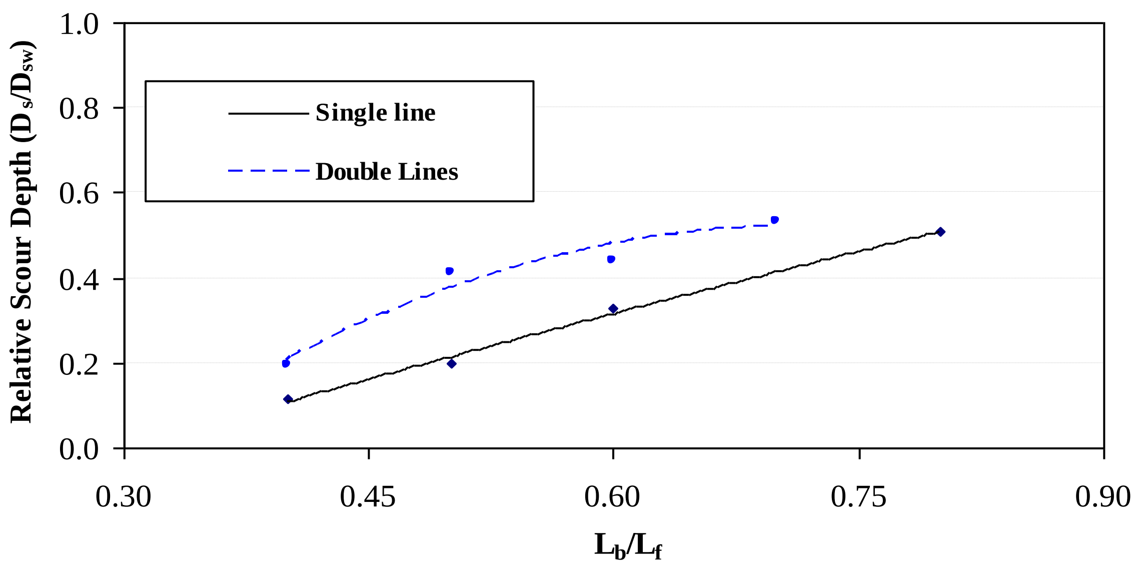



**Figure 8. Relationship between relative scour depth $D_s/D_{sw}$ and $L_b/L_f$, ($F_{r1}$= 4.60 and $H_b$ = 1.33$D_o$)**

## 3.3 Effect of semi-circular baffle blocks on scour hole length

Fig. 8 to 12 present the relative maximum length of scour, $L_s/L_{sw}$ versus initial Froude number, $F_{r1}$. For all considered arrangements of baffle blocks with all tested values of $H_b/D_o$ and $F_{r1}$, the values of $L_s/L_{sw}$ were < 1.0. This means that the all tested baffle systems reduce the scour length for all used flow conditions comparing to the case where no baffle was used. For all considered arrangements of baffle blocks with all tested values of $H_b/D_o$, the value of $L_s/L_{sw}$ decreases as $F_{r1}$ increases. For all considered systems of baffle blocks, the initial Froude number, $F_{r1}$ has small effect on the value of $L_s/L_{sw}$, except for the value of $L_b/L_f$>0.6and $H_b/D_o$= 0.334. For all considered baffle position, and for $H_b/D_o$= 1.334, the single row gives the lowest values of $L_s/L_{sw}$.

This confirms that for higher values of baffle's height, the double rows and fully baffled floor acted as a submerged weirs and thus they produce more scour length than those produced by the single row of semi-circular baffle blocks.

According to Fig. 13, For the case of fully baffled floor, the value of $L_s/L_{sw}$ decreased as the value of $H_b/D_o$ increased except for the value of $H_b/D_o$= 0.33. For all considered arrangements of single and double line baffle blocks, increasing the value of $H_b/D_o$led to decrease the value of $L_s/L_{sw}$.

For all considered arrangements of baffle blocks with all tested values of $F_{r1}$, the case of fully baffled floor give the smaller values of $L_s/L_{sw}$ for relatively smaller values of $H_b/D_o$. On contrary, the case of single line baffle blocks gave the smaller values of $L_s/L_{sw}$, for relatively higher values of $H_b/D_o$.

Referring to Fig. 14, for all considered arrangements of baffles with all tested values of $F_{r1}$, increasing the value of $L_b/L_f$ led to increase the values of $L_s/L_{sw}$. While, it is clear that the influence of $L_b/L_f$ on $L_s/L_{sw}$ increased as $H_b/D_o$ increased. This highlights that using smaller values of $L_b/L_f$ reduced the value of maximum scour depth. The single line baffle gave more reduction in the scour depth than the double line especially for higher values of $H_b/D_o$. This may be ascribed to the double line baffle blocks act as a submerged weir when used with higher values of baffle's heights and/or due to the balance time for experiments of double rows and fully baffled block not reached.

For all considered arrangements of baffle blocks with all used values of $F_{r1}$, the influence of the $H_b/D_o$ on the value of $L_s/L_{sw}$ is more significant than that of the value $L_b/L_f$.
Single row of baffle blocks caused more reduction for the scour hole length under all considered flow conditions. Using $L_b/L_f$= 0.4 and $H_b/D_o$= 1.33, gives the maximum reduction in the scour length which ranged from 77.06 % to 93.66%. These are very consistent with the findings of

**Edward (1959)** and **El-Masry & Sarhan (2000)**.
The most efficient case of the double line baffle blocks using $H_b/D_o$=1.33 and $L_b/L_f$=0.4, yields a reduction of scour hole length ranged from 78% to 90%.Though, The most efficient case of fully baffled floor using $H_b/D_o$=0.66, gives a reduction in the scour hole length ranged from 50% to 80%.

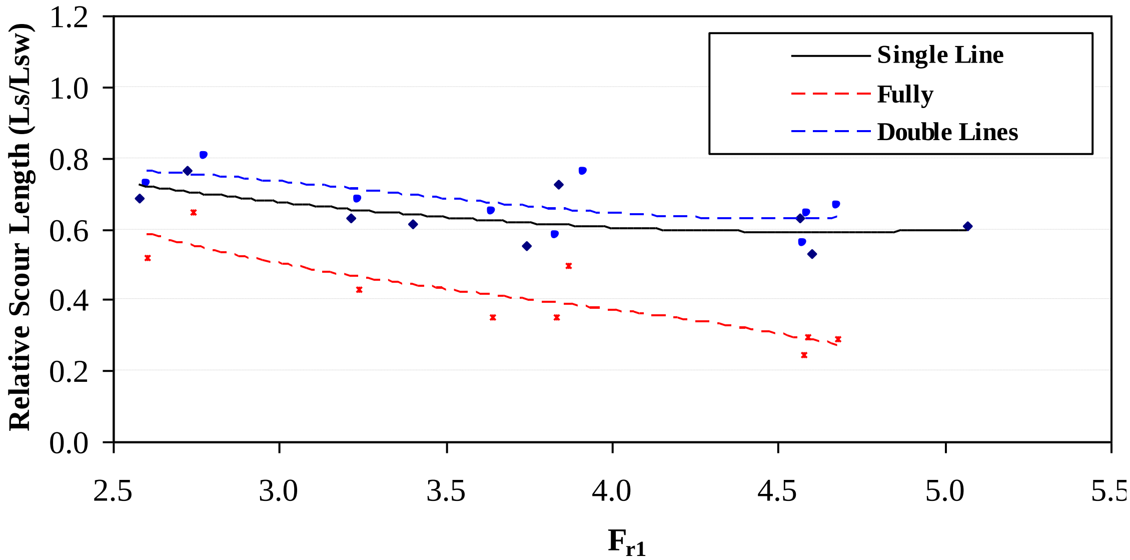



**Figure 9. Relationship between relative scour length $L_s/L_{sw}$ and $F_{r1}$, ($L_b$ = 0.4 $L_f$ and $H_b/D_o$ = 0.334)**

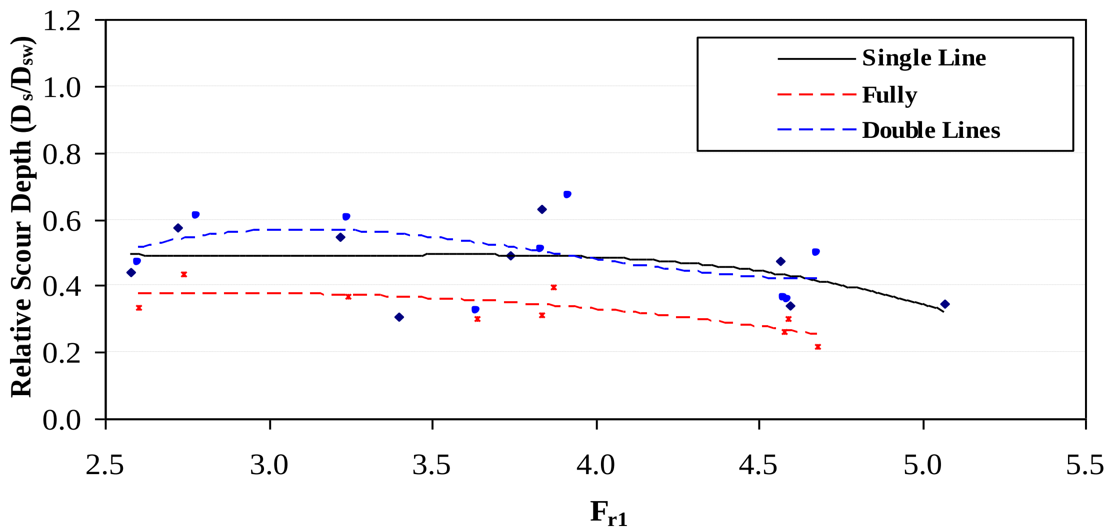



**Figure 10. Relationship between relative scour length $L_s/L_{sw}$ and $F_{r1}$, ($L_b$ = 0.6 $L_f$ and $H_b/D_o$ = 1.0)**

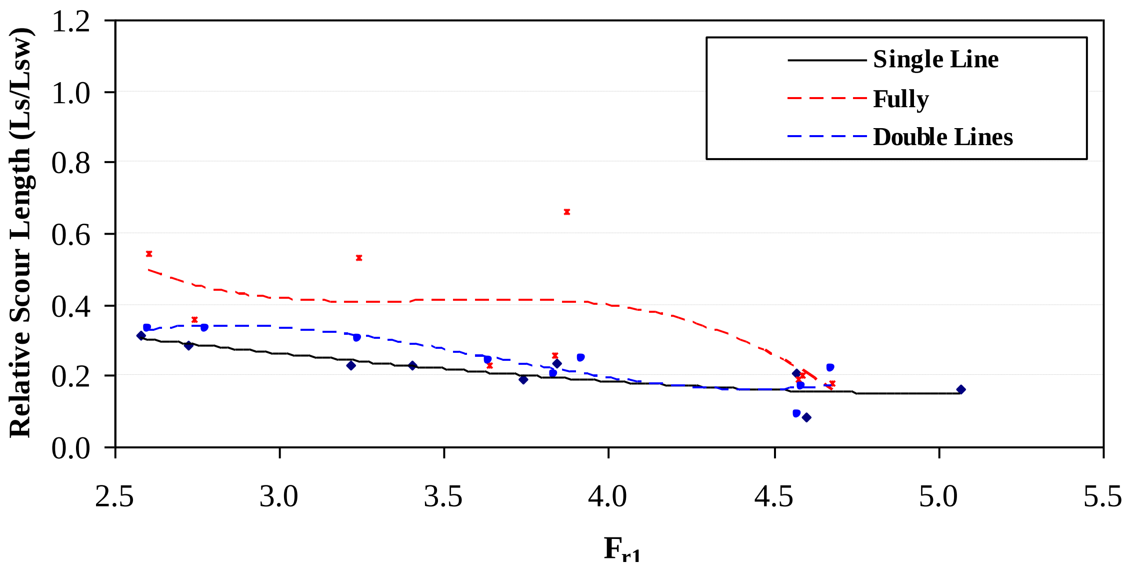



**Figure 11. Relationship between relative scour length $L_s/L_{sw}$ and $F_{r1}$, ($L_b$ = 0.5 $L_f$ and $H_b/D_o$ = 1.33)**

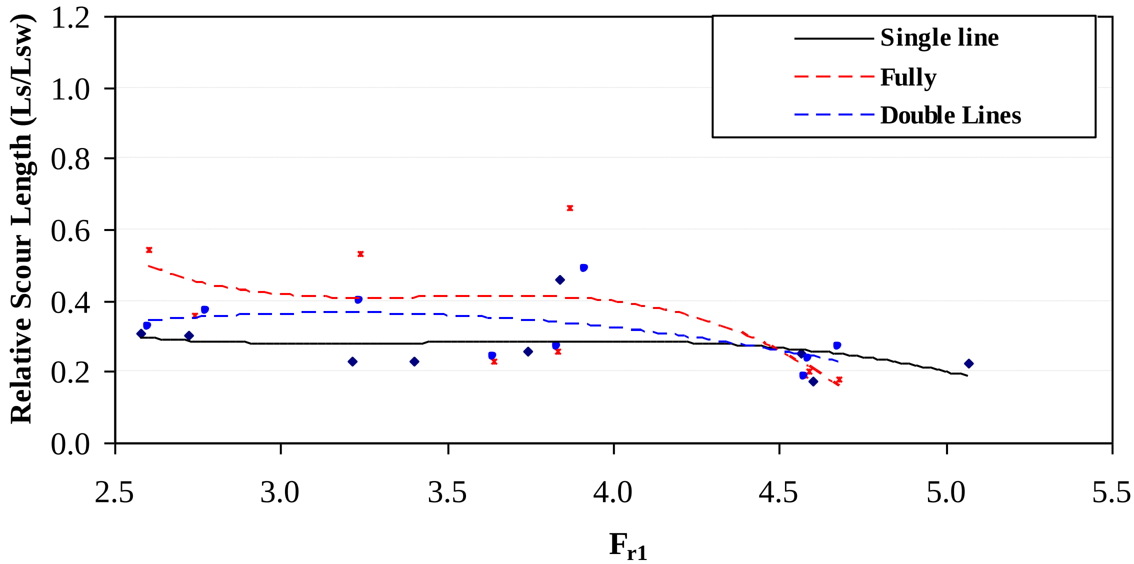



**Figure 12. Relationship between relative scour length $L_s/L_{sw}$ and $F_{r1}$, ($L_b$ = 0.8 $L_f$ and $H_b/D_o$ = 1.33)**

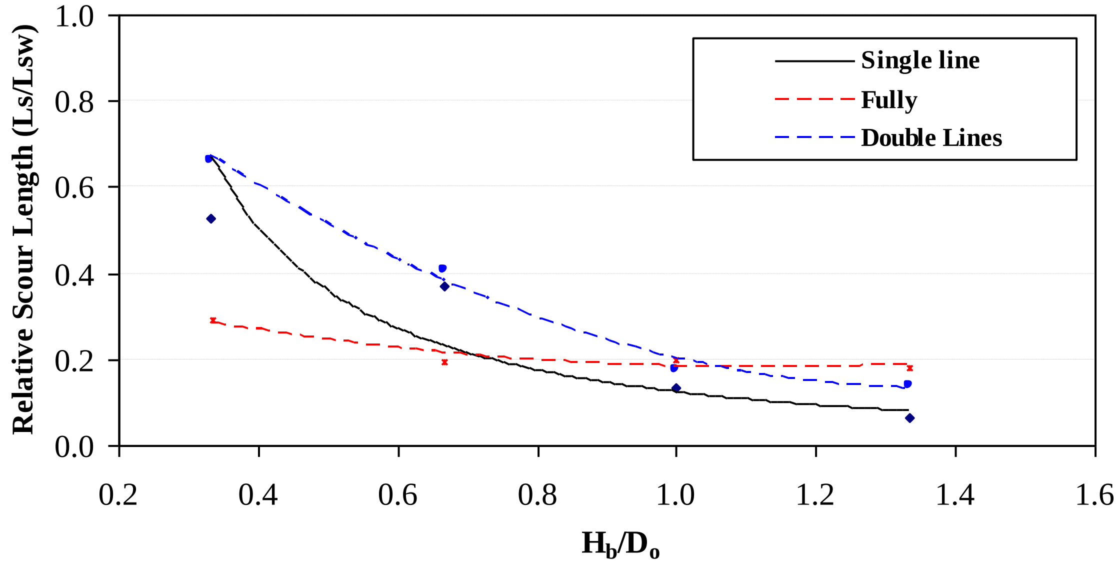



**Figure 13. Relationship between relative scour length $L_s/L_{sw}$ and $H_b/D_o$, ($F_{r1}$= 4.60 and $L_b$ = 0.4 $L_f$)**

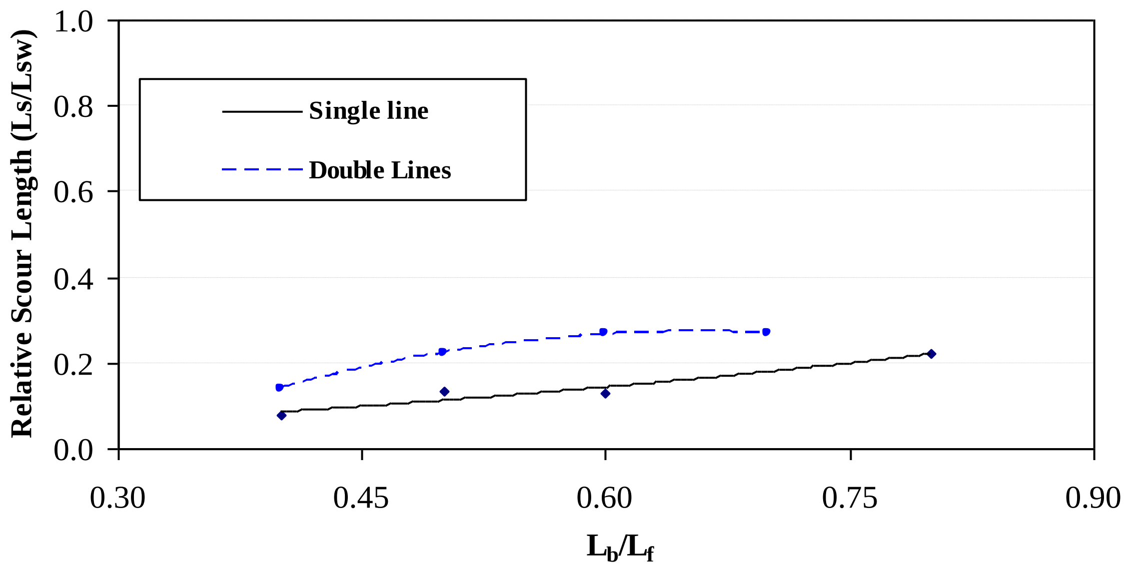



**Figure 14. Relationship between relative scour length $L_s/L_{sw}$ and $L_b/L_f$, ($F_{r1}$= 4.60 and $H_b$ = 1.33$D_o$)**

## 4 CONCLUSIONS

The comparison between experimental studies of local scour downstream of a Fayoum type weir with a horizontal apron equipped with single row, double rows, or fully baffled blocks, led to the following conclusions:

- For all considered arrangements of baffle blocks with most tested values of $F_{r1}$, the case of fully baffled floor gave the smallest values of $D_s/D_{sw}$.
- A single line of baffle blocks gave smaller values of $D_s/D_{sw}$ than double line baffle blocks except for $F_{r1} > 4.0$, and $H_b/D_o = 0.334$.
- The case of single line baffle produced more reduction in the scour depth than the double line especially for higher values of $H_b/D_o$.
- For all considered baffle position, and for $H_b/D_o$= 1.334, the single row resulted in the lowest values of $L_s/L_{sw}$

- The case of fully baffled floor yielded the smaller values of $L_s/L_{sw}$ for relatively smaller values of $H_b/D_o$.
- The case of single line baffle blocks produced the smaller values of $L_s/L_{sw}$, for relatively higher values of $H_b/D_o$.
- The single line baffle indicated more reduction in the scour depth than the double line especially for higher values of $H_b/D_o$
- For single line of baffle blocks, the value of $H_b/D_o$= 0.334 results in higher values of $D_s/D_{sw}$ and the value of $H_b/D_o$= 1.33 produces lower values of $D_s/D_{sw}$.
- The use of double rows baffle blocks arranged in staggered manner is not efficient with higher values of $H_b/D_o$.
- The fully baffled floor system was suitable for almost the tested flow conditions. Single and double lines of baffles are suitable for specific conditions of flow.

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## SYMBOLS

The following symbols were used through this research:

| | | |
|---|---|---|
| $b$ | =Basin width | [L] |
| $D_o$ | =Outer baffle's diameter | [L] |
| $D$ | =Inner baffle's diameter | [L] |
| $D_s$ | =Maximum scour depth | [L] |
| $D_{sw}$ | =Maximum scour depth without baffles | [L] |
| $D_{50}$ | =Sediment size (50% finer) | [L] |
| $F_{r1}$ | =Initial Froude Number | [-] |
| $L$ | =Distance between baffles lines | [L] |
| $L_b$ | =Distance between baffles line and the toe of the weir | [L] |
| $L_f$ | =Floor length | [L] |
| $L_s$ | =Maximum scour length | [L] |
| $L_{sw}$ | =Maximum scour length in case of no baffles | [L] |
| $H_b$ | =Baffle's height | [L] |
| $Q$ | =Discharge | [$L^3T^{-1}$] |
| $R_e$ | =Reynolds number | [-] |
| $S$ | =Clear distance between baffles in the normal direction of flow | [L] |
| $t$ | =Thickness of baffle | [L] |
| $Y$ | =Tail water depth | [L] |
| $y_1$ | =Initial water depth of a hydraulic jump | [L] |
| $y_2$ | =Sequent water depth of a hydraulic jump | [L] |

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