3rd International Engineering Conference on Developments in Civil & Computer Engineering Applications 2017 (ISSN 2409-6997)

Evaluation the hydraulic performance of W shape Baffles in stilling basins

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doi: 10.23918/iec2017.01

ABSTRACT

The utility of baffles built downstream in stilling basins is to dissipate the kinetic energy, adjust the location of hydraulic jump and prevent local scour downstream the stilling basin. Most investigations concentrated on the shape of baffle blocks. In this study, the hydraulic performance of a new shape (as W shape) baffle was tested. Three W baffle models were made of fiber glass, with different angles (45°, 60° and 75°). The range of the discharges in a glass channel are from 76 to 279 cm^3/s/cm. These discharges were used and controlled in such a way that the Froude number for all the tests upstream the models ranged from 4.5 to about 10.5. Generally, the results showed that all models contribute an increase of *E%*, but the baffle with an angle of 60° and L_b = 10 cm gave a height value of *E%* close to 85%. Also, at this angle, L_b gave the minimum relative length of jump. According to the results of this study, it can be considered that the W shape baffle is more efficient than other shapes since it provide a high dissipation of energy and lowering dimensions of the stilling basin. So, due to high dissipation of hydraulic energy and lower length of hydraulic jump in W shape baffles, it is recommended to be used in prototype future design of stilling basins.

Keywords: Hydraulic structures, hydraulic performance, Stilling basins, Baffles, Hydraulic jump.

1. INTRODUCTION

The stilling basins are hydraulic structures usually follow the spillways, gates and chutes to push away and reduce the hydraulic flow energy. The baffle blocks are considered as the main accessories which are normally installed in the stilling basins. The main utility of such accessories are to shorten the length of the hydraulic jump, dissipate additional hydraulic energy by increasing water turbulence, stabilizing the hydraulic jump in position of the stilling basin, and to protect the downstream floor from erosion and local scour. These objectives lead to decrease the initial cost of construction for the stilling basins. Numerous investigators study the effect of baffle blocks on the energy dissipation in stilling basins [Farhoudi and Narayanan, 1]. Farhoudi, J and Volker, R.E. [2] studied the behavior of water flow and calculated the drag force over the baffle blocks. Ghodsian M., et al. [3] designed a new method by studying the effect of baffle blocks on the dimensions of stilling basin to dissipate hydraulic energy. Their study indicated that energy dissipation increased when baffle blocks as near as the beginning of stilling basin. Carolo F.G., et al. [4] tested experimentally the jump over a different sizes of gravel beds. The size of gravel ranged between 0.46 and 3.2 cm with Froude numbers between4 to 12. They found that hydraulic jump in rough bed is less than in smooth bed. Shafai, M.B. and Neisi, K. [5] examined the effects of simulated rough features on the sequent water depth.

Their results indicated that the existence of a rough components leads to decrease the sequent water depth and reduce the hydraulic jump by about 40% of the classic basins. Influence of the position of crosswise end sill on depth and length of a hydraulic jump in stilling basin were evaluated by Alikhani, A., et al. [6].Their experimental results assured the importance of end sill on the energy dissipation. AboulAtta, N., et al [7] studied experimentally a new shape of baffles (T-shape).They found that the best roughness intensity between7.2% to 8.8% gave a high dissipation energy was about 70%.

In this study, the hydraulic performance of a new shape of baffles as (W shape) was tested by evaluating its influence and location on dissipation of the hydraulic flow energy and length of the stilling basin. In addition to its effect on the local scour and erosion downstream the stilling basin.

List of symbols

A_1	area at section (1)
A_2	area at section (2)
B	width of channel
CD	drag coefficient
E1	specific energy at sec 1
E2	specific energy at sec.2
E%	Energy dissipation percent
F1	Froude number
Fd	drag force
g	gravitational acceleration
L_b	distance between toe of spillway to beginning of baffles
L_j	hydraulic jump length
P_1	pressure at section 1
P_2	pressure at section 2
Q	discharge
V_1	flow velocity
y_1	initial flow depth

2. THEORETICAL APPROACH

2.1 DIMENSIONAL ANALYSIS

The sequent water depth (y_2) and hydraulic jump length (L_j) depends on the flow conditions before the W shape baffle. These conditions (initial flow depth (y_1), the distance between toe of spillway to beginning of baffles (L_b), flow velocity (V_1), the gravitational acceleration (g) and the angle of the baffles (θ)) can be formed in the following functional equation:

$$L_j \text{ or } y_2 = f_1 (y_1 , V_1 , L_b , g , \theta) \qquad (1)$$

The Buckingham's Π theorem can be used to formulate the next dimensionless equation:

$$y_2 / y_1 \text{ or } L_j / y_1 = f_2 (L_b / y_1 , F_1 , \theta) \qquad (2)$$

Where:

y_2/y_1 = sequent water depth ratio . L_j/y_1 = relative length of jump. F_1 = Froude number at upstream section just before the baffles.

2.2 ENERGY DISSIPATION RATIO

The energy dissipation ratio *E%* can be verified from the energy and continuity equations by applying these equations between sections (1) and (2) as shown in Fig.(1).

$$E\% = \frac{E_1 - E_2}{E_1} = 1 - \frac{F_1^2 + 2(y_2/y_1)^3}{(y_2/y_1)^2(F_1^2 + 2)} \qquad (3)$$

In which, E_1 and E_2 are the specific energy at sections (1) and (2) respectively.

2.3 DRAG FORCE COEFFICIENT CD

The drag force can be verified from the momentum and continuity equations as follows:

The momentum equation in the direction of flow between section (1) and section (2) Fig.(1) can be derived as follow:

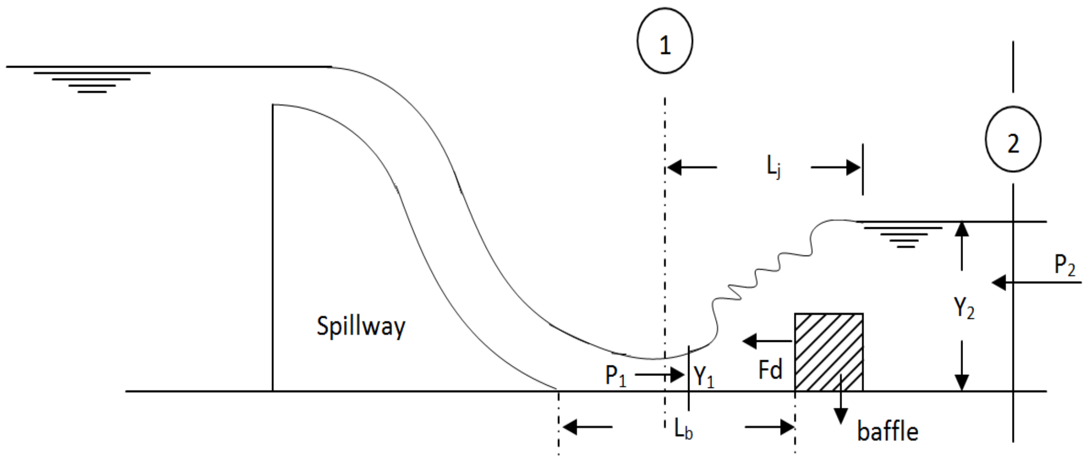


FIGURE 1. Definition sketch of experimental work

$$P_1 A_1 - Fd - P_2 A_2 = \rho\, Q\, (V_2 - V_1) \qquad (4)$$

$$\gamma\, y_1^2 B/2 - Fd - \gamma\, y_2^2 B/2 = \rho(y_2 V_2^2 - y_1 V_1^2) \qquad (5)$$

Continuity equation between sections (1) and (2) :

$$y_1 V_1 = y_2 V_2 \qquad (6)$$

From equation (5) and (6) we get :

$$Fd=(B/2)\gamma\, y_1^2(1-(y_2/y_1)^2) - \rho y_2 V_2^2\,(1-y_2/y_1) \qquad (7)$$

Drag coefficient (*CD*) can be calculated from the following equation [Durgaiah, R. 8]:

$$CD=\frac{Fd}{\frac{1}{2}\rho V_1^2 A_1} \qquad (8)$$

Due to the shape of the models (W shape), an additional spacing factor was added to the denominator of the above equation referring to the ratio of baffle width to the channel width as:

$$\eta=\frac{w_b}{B} \qquad (9)$$

Where: η= spacing factor*;* and w_b = baffle width.

It can be noted that: for baffle walls, η =1, for baffle blocks, $\eta < 1$ and in this study, $\eta > 1$.

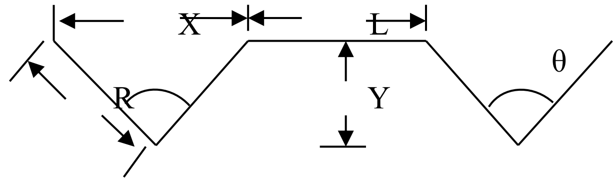
According to equation (9) the spacing factor was calculated, shown in table (1), and its values were used for calculating *CD* in equation (10).

$$CD=\frac{2Fd}{\eta\rho V_1^2 A_1} \qquad (10)$$

3. EXPERIMENTAL WORK AND MEASUREMENTS

The experimental program was prepared by a recirculating horizontal channel with smooth glass side walls (Figure 2). The channel is 3 m length, 0.2 m width and 0.3 m depth. The discharges were measured by a pre-calibrated sharp-crested weir installed at the inlet of the channel. The range of the discharges (76 to 279 $cm^3/s/cm$) were used and controlled in such a way that the Froude number for all tests upstream the models ranged from 4.5 to about 10.5 .Three W baffle models were manufactured from fiber glass. One of these models was shown in Fig (3). The dimensions of all models were shown in table (1). A spillway (Ogee type) was fixed upstream the channel to yield the required hydraulic jump. A gate was applied at end of the channel to adjust the tail water depth. The water depths were measured at a different locations with a calibrated point gauge. Models were fixed on the bed of the channel downstream of the spillway at distances of 5, 10 ,15 and 20 cm.

TABLE 1.
Shows the Dimensions of the tested models parameters



Angle θ	X cm	Y cm	R cm	L cm	η
45	6	7.3	7.8	8	1.96
60	6	5.2	6	8	1.6
75	6	4	5	8	1.4

FIGURE 2. General view of the recirculation rectangular channel

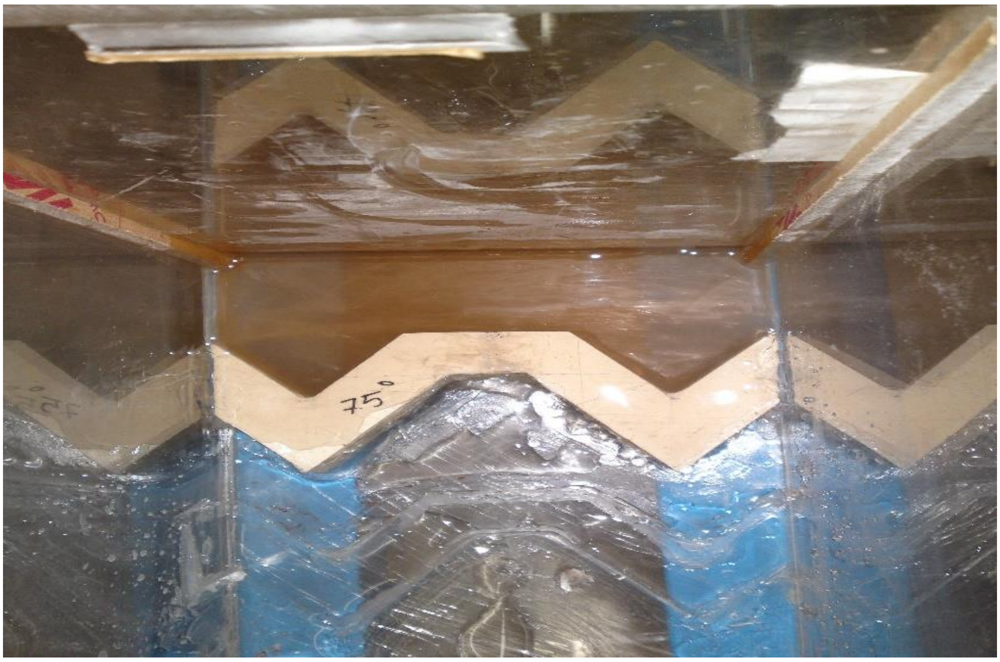


FIGURE 3. One of the W baffle models at angle 75°

4. ANALYSIS AND DISCUSSION OF RESULTS

The variation between the main flow characteristics *E%*, L_j/y_1 , y_2/y_1 and *CD* versus initial Froude number F_1 will be discussed and presented as follows :

4.1 ENERGY DISSIPATION RATIO E%

Figures (4, 5 and 6) shows the variation of energy dissipation ratio *E%* versus initial Froude number F_1 for different L_b and for angles 75° , 60° and 45° respectively . It reveals from figures that when L_b= 10 cm, it gives the highest *E%*. But generally, the effect of L_b is almost similar for the range used which indicating a general increasing trend for increased F_1. On the other hand, all models contribute to increase the

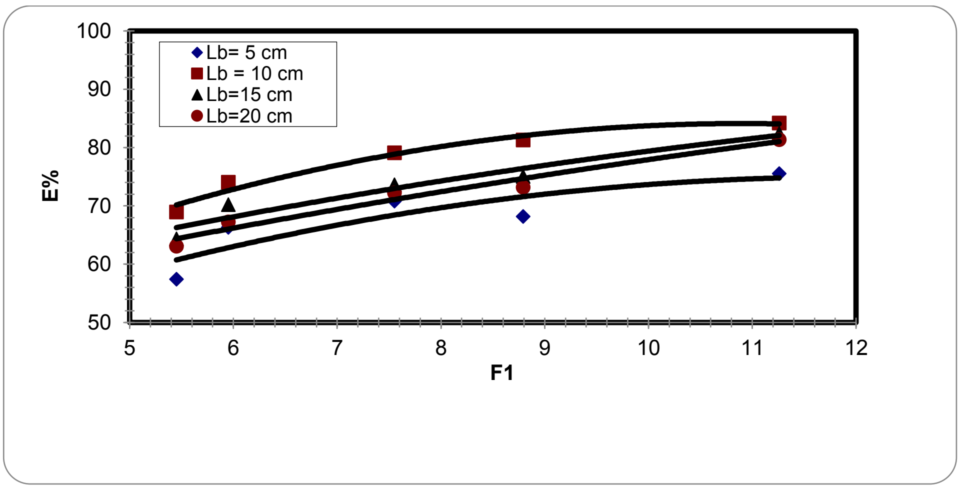


FIGURE 4. Relation between E% and F1 for different

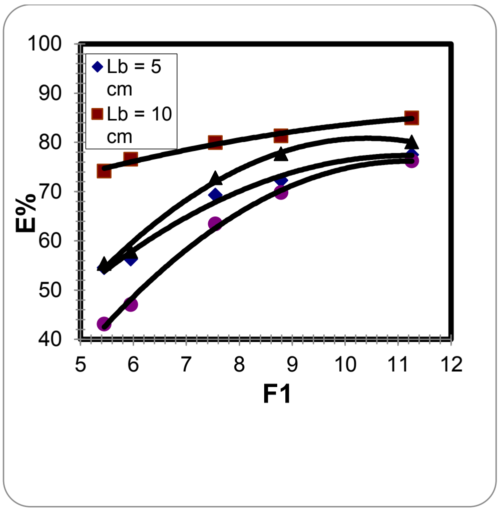


FIGURE 5. Relation between E% and F1 for different Lb at angle 60

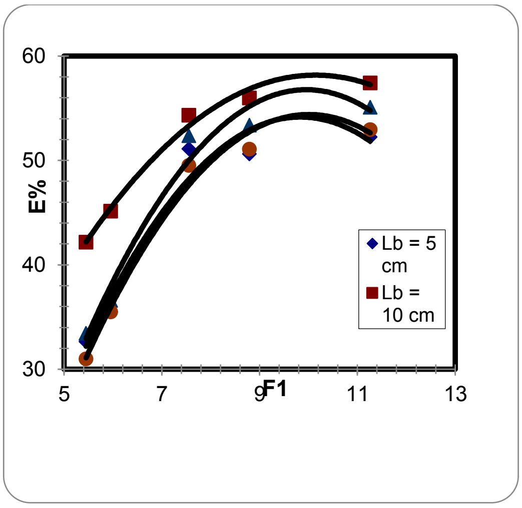


FIGURE 6. Relation between E% and F1 for different Lb at angle 45

energy dissipation percent *E%* .But the most of it is when the angle was 60° and L_b = 10 cm which gave *E%* close to 85%. This was obtained since this baffle leads to increase the retrace of the flow and give a higher conflict to water flow due to the correspondence of the triangle arms

4.2 THE RELATIVE LENGTH OF JUMP L_J/Y_1

The relative length of jump, Lj/y_1, is a function of initial Froude number F1 for different L_b and for angles 75° and 60° respectively. Within the range of experimental data, figures (7and 8) show that the relative length of jump almost increases linearly with the increase of Froude number. It was appeared from both figures that when L_b= 10 cm gives the minimum relative length of jump, but the lowest when the angle is 60°.

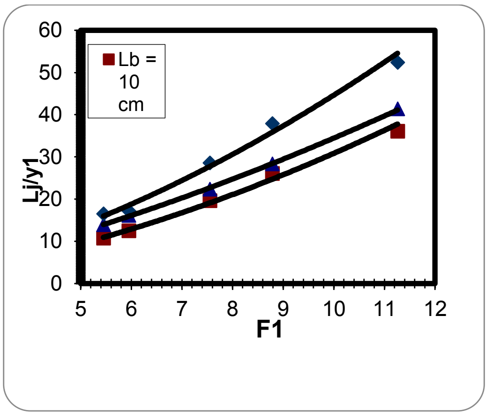


FIGURE 7. Relation between Lj/y1 and F1 for different Lb at angle 75

IO Y_2/Y_1

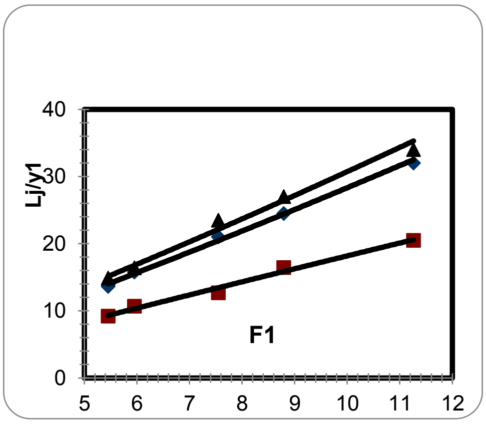


FIGURE 8. Relation between Lj/y1 and F1 for different Lb at angle 60

Figures (9, 10 and 11) illustrate the relation between the sequent depth ratio y_2/y_1 and initial Froude number F1 for the hydraulic jump that forced by the baffles. All figures confirm an increase in the sequent depth ratio with the increase of F1. This increase is almost better when L_b =10 for all figures, but the best is when the angle is 60°.

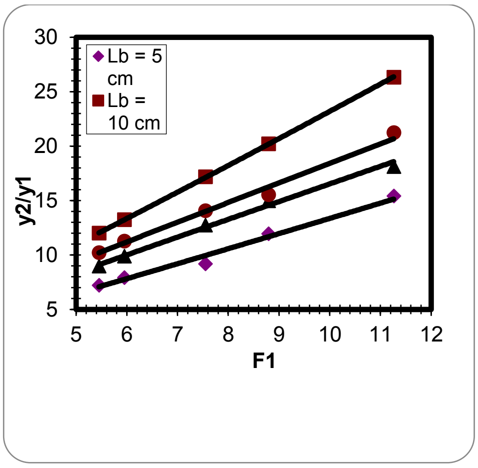


FIGURE 9. Relation between y2/y1 and F1 for different Lb at angle 75

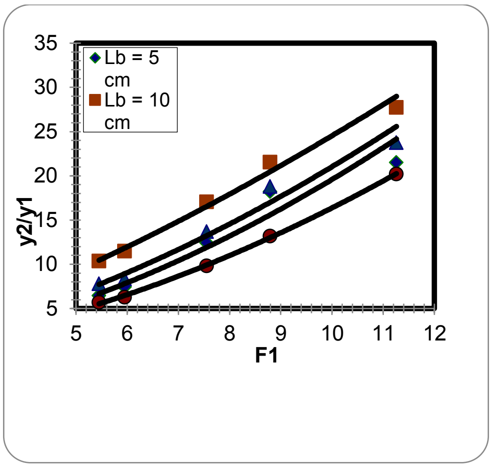


FIGURE 10. Relation between y2/y1 and F1 for different Lb at angle 60

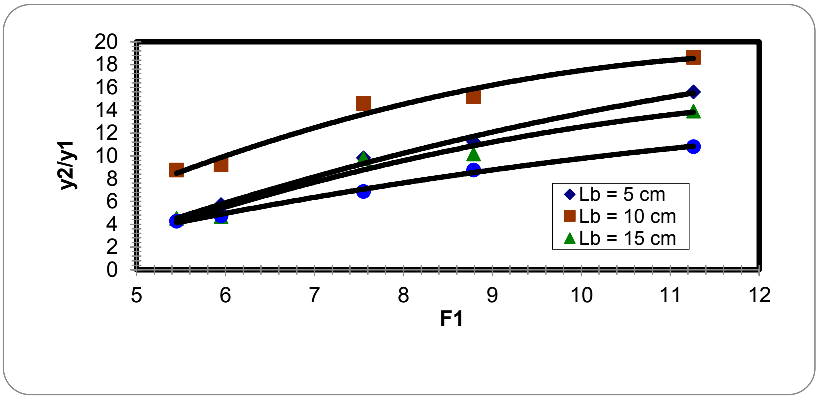


FIGURE 11. Relation between y2/y1 and F1 for different Lb at angle 45

4.4 DRAG FORCE COEFFICIENT CD

The relation between CD and F1 were explained in Figs. (12, 13and 14) for angles 75° , 60° and 45° respectively. In all these figures, it was evident that the drag coefficient was decreased inversely with initial Froude number. Furthermore, it was appeared that minimum CD when L_b equal 10 and angle 60° .

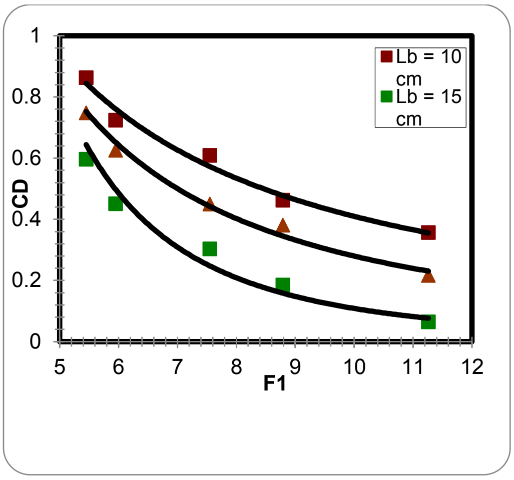


FIGURE 12. Relation between CD and F1 for different Lb at angle 75

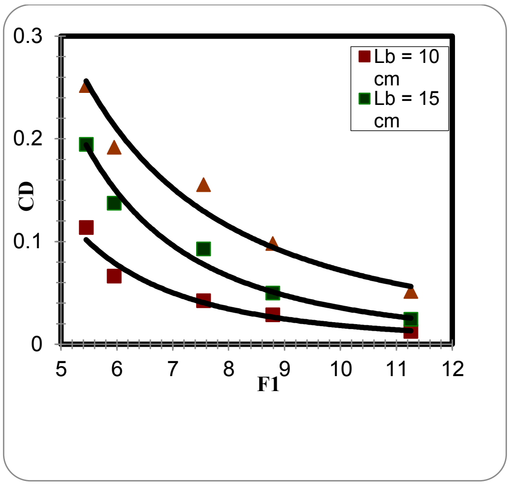


FIGURE13. Relation between CD and F1 for different Lb at angle 60

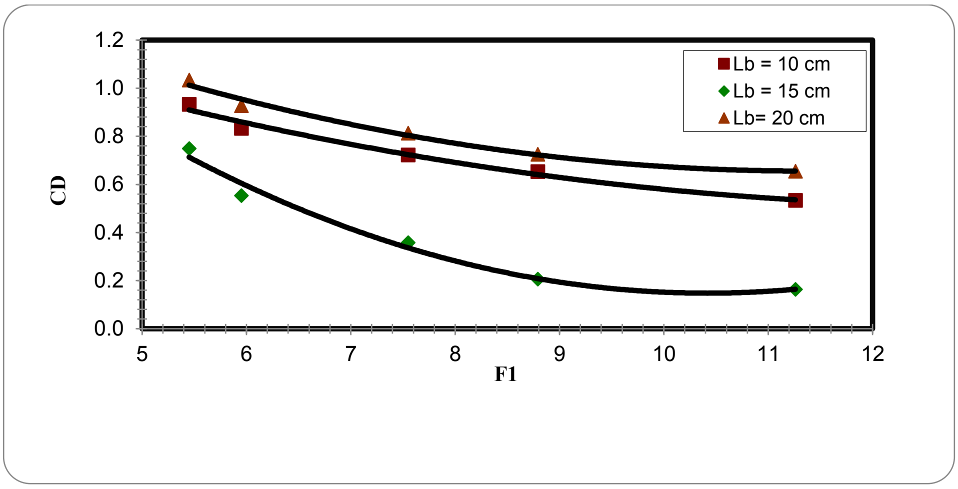


FIGURE 14. Relation between CD and F1 for different Lb at angle 45

The empirical power equation [from Fig. (13) ,L_b= 10 cm] could be formulated as follows:

$$CD=12.3(F1)^{-2.83} \qquad (12)$$

Equation (12) fits the observations with a confidence level of $R^2 = 0.98$.

5. CONCLUSIONS AND RECOMMENDATIONS

Based on results and analysis of this study, the following main conclusions were summarized as:

a. All models contribute to increase *E%*, while the baffle with an angle of 60^o and L_b = 10 cm gave *E%* close to 85%. This is because that this baffle leads to increase the retrace of the flow and give a higher conflict to water flow due to the correspondence of the triangle arms.
b. When L_b= 10 cm, the baffle gave the minimum relative length of jump, but the lowest were given when the angle is 60^o.
c. In all models, the drag coefficient was decreased inversely with initial Froude number. Furthermore, it was appeared that minimum CD when L_b equal to 10 and angle 60^o .
d. It could be considered that the W shape baffles are more efficient than other shapes of baffles since they gave high dissipation of energy and lowering length of the stilling basin. So, according to this study, it can be recommended to use this shape of baffles in the prototype future design of stilling basins.

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