STUDYING THE NON-TRADITIONAL SILL FORMS ON ENERGY DISSIPATORS

By

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Abstract:

In the context of dissipating the energy in thewater flowingthroughcontrol structures, this research was initiated in order to distract a large portion of the energy before reaching earth bed of the canal. This was achieved by carrying out experiments to a model with a non-traditional sill. A crescent shaped (Y) fixed at its lower part withdifferentdiameter(d)to lintel heightlintel(h_o)ratio(i.e. d / h_o = 1.00 - 0.85 - 0.67) where their upper part is rotated about the center by three angles (0, 10 and 20o). Placed at arelative distance from the gate(i.e. L_b/ L_f = 0.187, 0.25, 0.375)in order to investigatethe impact of theseratiosin reducing thehydraulicjump length. For comparison purposes, trials were conductedwithout lintel.

The experiments were carried out in theHydraulicLaboratory of Faculty of Engineering-Al-Azhar UniversityinCairo. The experimental channel is 4.0m long and is of squared cross section(30 cm × 30cm)withtransparentvertical sides equipped withtwoultrasounds, one monoand the othermultiin order to measure thelevelsandwater depthsas well as thelevelsanddepthsof the channel bottom. The researchconcludedthat the bestenergydissipationratio was(d / h_o= 1.00)witha relativefloor length 0.25.

Index Terms: Hydraulic Jump, Control of Jump, Energy Dissipations and Sills

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1. INTRODUCTION

The hydraulic jump is one of the most frequently encountered cases of rapidly varying flows. This occurs when a supercritical flow changes to subcritical flow, which is required to maintain the regime conditions in mobile boundary channels. Water passing through the sluice gates or flowing over spillways has tremendous velocity because of restricted waterway and high hydraulic gradient which changes its state rapidly from low stage to high stage. The result is rapid heaping of water surface. For jump occurrence, there must be a flow impediment downstream. Usually, engineers purposely install impediments in channels in order to force jumps to occur. Concrete blocks may be installed in a channel downstream of a spillway in order to force a jump to occur thereby reducing the velocity and energy of the water..

In this study, the hydraulic performance and efficiency of using non-traditional sill were investigated, experimentally. A crescent shaped (Y) was examined as a non-traditional sill. A theoretical study was conducted using numerical analysis technique to detect the relationships between the various parameters and variables. The experimental study was conducted in a glass wall flume of length of 4 m. Three relative diameters (d/h_0 =1.00, 0.85, 0.67), Three relative angles (0.0o, 10 o and 20o) and relative distance (L_b / L_f = 0.375, 0.25, 0.187) were examined. It was found that the satisfactory hydraulic performance was achieved when relative diameters of 0.85 and relative distance of 0.25 was used.

Primarily, literature was reviewed. Then theoretical so as experimental investigations were conducted. Results were analyzed and discussed. Based on this analysis, conclusions were deduced and recommendations were given forward. This is presented in this paper under the following headlines: Literature Review

- Theoretical investigation
- Experimental Investigation

- Analyzing, presenting and discussing the results
- Conclusions and recommendations

2. LITERATURE REVIEW

Many researchers investigated the required length to ensure the safety of the foundation of the hydraulic structures. Among them, for example, are the following:

- *In 1955, U.S. Bureau of reclamation (2)* conducted a series of measurements to determine the length of the hydraulic jump was conducted by the. In these experiments, Froude number varied from 2 to 20. An analysis of the experimental data indicated that a good relationship between the length and the height of the hydraulic jump existed showing that the length of the jump is 6.9 times the jump height:
- *In 1994, Abdellateef M. (1)* investigated floor jets for the case of the submerged jump. The optimum length of perforated bed in a stilling basin with diverging walls was computed by using the submerged hydraulic jump. Different lengths of floor jets of constant diameter were used.
- *In 2006,Waleed Abdel-Galeel. (5)* Studied the effect of inclined jets on hydraulic jump in downstream gate opening. He proposed 300, 450 and 600 inclination angels for jets. He found the side jets dissipate the energy downstream the sluice gate by about 38% compared with the case on no jets.
- *In (2008) Mostafa Ali, (3)* had used aprons of formed surface as energy dissipaters downstream hydraulic structures. He found that the scour hole dimensions increase with the increasing Froude number Fr, Relative floor length (L_b/L_f) for all shapes and arrangements of sills.

- ***In (2010) Osama Alashry, (4)*** studied the combination of vertical and horizontal concavities on energy dissipation. He found that at X = 1.67 the best values of y_2/y_1 occured.

- ***In (2014) Ahmed Helmy(6)*** studied the effect of Y shape sill on hydraulic jumps, figure (2.17). He studied three angles (45□, 30□, 15□) and three relative length of floor/Lf = (0.27, 0.22 and 0.17). He found the best angel is 30 and the best relative length of floor is Lb/Lfis 0.22.

- *In (2009) Bejestan, M.S. and K. Neisi,(7)* studied a new roughened bed hydraulic jump stilling basin, figure (2.7). To reach such idea, first a new expression was developed for sequent depth and hydraulic jump length. Then, hydraulic jumps were conducted on a bed of prismatic roughness elements in a rectangular flume in order to investigate the jumps' effects on the characteristics of stilling basins. The roughed elements are glued on the bed of the flume downstream of ogee spillways in such a way that the incoming water jet is just above the element surface. Each rough element shape was tested under different Froude numbers, ranging 4.5 to 12. They found that the reduction of required tail water depth is about 26% and the hydraulic jump length is reduced about 41%. The rough element does not protrude into the flow and therefore they will not cause any cavitation.

- ***In (1985) YousriZaghlool, (8)*** used an end concave circular sill to dissipate energy. According to Buckingham's theory, he studied the parameters, which would have effect on the flow downstream gate.

3. THEORETICAL INVESTIGATION

Theoretical study has been conducted using numerical analysis method to detect the relationships between the various parameters and variables of a crescent shaped (Y) sill and hydraulic jump behind vertical gates. Figures (1) and (2) present all parameter and geometry. Functional relationships were obtained between the relative lengths of the hydraulic jump (L_j / L_{jw}), and Froude number(F_r) and the relative scour depth (D_s / D_{sw}) with Froude number(F_r) as well as the relativscour length and the relative scour depth (L_s / L_{sw}), with Froude number(F_r).

Depths upstream and downstream the jump are denoed by Y_1 and Y_2 Respectively.

ΔY is the height of the hydraulic jump i.e.

$$\Delta Y=(y_2-y_1) \qquad \text{.................. (1)}$$

Length of jump denoted by Lj.

$$L_j = 6.9\Delta y \qquad \text{(Bureau of Reclamation) .... (2)}$$

It can be readily shown that (y_2) is given in terms of (y_1) for a rectangular channel as follows:

$$y_2 = -\frac{y_1}{2} + \sqrt{\frac{2v_1^2 y_1}{g} + \frac{y_1^2}{4}}$$

(Bureau of Reclamation)..............................(3)

But the Froude number (F_r) is as follow:

$$F_r = \frac{v}{\sqrt{gy}} \qquad \text{...................... (4)}$$

If the Froude number (Fr) is introduced to equation (3), the Bureau of Reclamation becomes:

$$y_2 = \frac{y_1}{2}(\sqrt{1+8F_r^{\ 2}} - 1) \qquad \text{................ (5)}$$

The study variables can be expressed as follows:

$$\Phi = f(L_f, L_b, L_j, t, h, B, y_1, y_n, , Q, \rho, g, \mu, S.G, Ø, D_s, L_s, L_m) \quad \text{.. (6)}$$

where, B is the channel width, Q is the discharge,ρ is the density of fluid, g is the gravity acceleration, μ is the dynamic viscosity , S.G is the specific density and Ø is the selected soil diameter. Soil tested wasn't changed, so the parameters Ø and S.G could be deleted from the variables. According to Buckingham Pi-theorem, the general form of relationship between these variables may be written as follows:

$$\phi = \left(\frac{L_f}{B},\frac{L_b}{B},\frac{L_j}{B},\frac{t}{B},\frac{h}{B},\frac{y_1}{B},\frac{y_n}{B},\frac{Q^2}{B^5 g},\frac{\rho Q}{B\mu},\frac{D_s}{B},\frac{L_s}{B},\frac{L_m}{B}\right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \ (7)$$

Taking the properties of Pi-terms into account, the following relationship can be obtained:

$$\phi_1 = \left(\frac{L_b}{L_f},\frac{L_j}{y_1},\frac{L_m}{L_s},\frac{t}{h},,\frac{D_s}{y_n},Fr\right) \quad \ldots\ldots\ldots \ (8)$$

Where:

L_b / L_f is the relative floor length

L_j / y_1 is the performance of hydraulic jump

L_m /L_s is the relative scour length

t / h is the sill ratio

D_s / y_n is the relative scour depth

F_r is Froude number

y_n is tail water depth

Finally, the relationship could be written, as follows:

$$F_r = \phi\left(\frac{L_b}{L_f},\frac{L_j}{y_1},\frac{D_s}{y_n},\frac{t}{h},\frac{L_m}{L_s}\right) \quad \ldots\ldots\ldots\ldots\ (9)$$

4. EXPERIMENTAL INVESTIGATION

One hundred and twelve (112) tests were conducted. The experimental investigation was carried out in the hydraulic laboratory of the faculty of engineering, Al- Azhar University in Cairo. The flume consists of 30x30 cm rectangular steel frame with visible clear polycarbonate sides and is of 4.0 m length. The poly carbonate sides of the channel allow visual observation of the water surface, figure (3) and photo (1).

Three relative diameters (d) for height sill (h_o) were used in the experiments. The sills are made of poly carbonate with three relative (d/h_0) = (1.00 - 0.85 -0.67). The upper part rotated about center with three angles (0.0o, 10 o and 20o). They had constant width (t) of 0.30 m.

It was placed in the channel bed in the flow direction. The elements were placed at the positions relative to the inlet gate with relative floor length (L_b/L_f) equals to 0.187, 0.25 and 0.375, respectively. At these locations, the bed material (sand) was accurately leveled and the leveling accuracy was checked by means of a water gauge. The elements were fitted at a certain position. The required discharge was passed. The running time was started. The sequent depth y_2 was measured and the jump length L_j was measured from the leading edge of the jump to a point just downstream the top roller of the jump. The longitudinal scour whole profile was measured at intervals of 5 cm by means the gauge and Ultrasonic was their determination and their implementation by the team work, photo (1). The velocity distribution downstream the elements and the normal water depth were measured. The hydraulic jump was formed under condition of free flow downstream the gate. The jump was stabilized. Measurements were undertaken and observations were documented. Moreover; photos were captured, photo (2).

4. a. REPRESENTING THE RESULTS OF THE LENGTH OF JUMP

Figures (4), (5), (6), (7), (8), (9), (10), (11) and (12) for models A, B, C, D, E, F, G, H and I receptively, present the relationship between L_j/L_{jw} and F_r for different positions. From the figures it was clear that for all the considered positions and for all the tested values of F_r that all the values of L_j/L_{jw} are less than 1. This means that all models reduced the jump length under all considered flow conditions. Also, table (2) lists the models and the apron length. Model I decreased the jump length.

For case of model I and all considered flow conditions, it was obvious that the case of $(L_b/L_f) = 0.25$ provided a higher reduction percent to the jump length. Noticeable was that the reduction percent of jump length ranged between 62 % and 70 % compared to the case without a sill. In the case of $(L_b/L_f) = 0.375$ provided a smaller reduction percent to the jump length. Noticeable was that the reduction percent of jump length ranged between 48% and 64% compared to the case without a sill. For the case of $(L_b/L_f) = 0.1875$ provided reduction percent of jump length ranged between 53% and 68% compared to the case without a sill as presented in figure (12).

4. b. REPRESENTING THE RESULTS OF THE SCOUR LENGTH

Figures (13), (14), (15), (16), (17), (18), (19), (20) and (21) for models A, B, C, D, E, F, G, H and I, receptively, present the relationship between F_r and L_s/L_{sw} for different positions. From the figures it was clear that for all the considered positions and for all the tested values of F_r, all the values of L_s/L_{sw} are less than one. This means that all models reduced the scour depth under all considered flow conditions. Table (2) lists the models and the scour depth. Model E soundly decreased the apron length for $L_b/L_f = 0.25$.

For case of model I and all considered flow conditions, it was obvious that the case of $(L_b/L_f) = 0.25$ provided a higher reduction percent to the scour length. Noticeable was that the reduction percent of scour length ranged between 40 % and 55 % compared to the case without a sill. In the case of $(L_b/L_f) = 0.375$ provided a smaller reduction percent to the scour length. Noticeable was that the reduction percent of scour length ranged between 36% and 48% compared to the case without a sill. For the case of $(L_b/L_f) = 0.1875$ provided reduction percent of scour length ranged between 37% and 35% compared to the case without a sill as presented in figure (21).

4. c. REPRESENTING THE RESULTS OF THE SCOUR DEPTH

Figures (22), (23), (24), (25), (26), (27), (28), (29) and (30) for models A, B, C, D, E, F, G, H and I, receptively, present the relationship between F_r and D_s/D_{sw} for different positions. From the figures it was clear that for all the considered positions and for all the tested values of F_r, all the values of D_s/D_{sw} are less than 1. This means that all models reduced the scour depth under all considered flow conditions. Table (2) lists the models and the scour depth. Model I soundly decreased the depth scour.

For case of model I and all considered flow conditions, it was obvious that the case of $(L_b/L_f) = 0.25$ provided a higher reduction percent to the scour depth. Noticeable was that the reduction percent of scour depth ranged between 39 % and 50 % compared to the case without a sill. In the case of $(L_b/L_f) = 0.375$ provided a smaller reduction percent to the scour depth. Noticeable was that the reduction percent of scour depth ranged between 30% and 43% compared to the case without a sill. For the case of $(L_b/L_f) = 0.1875$ provided reduction percent of scour depth ranged between 31% and 46% compared to the case without a sill as presented in figure (30).

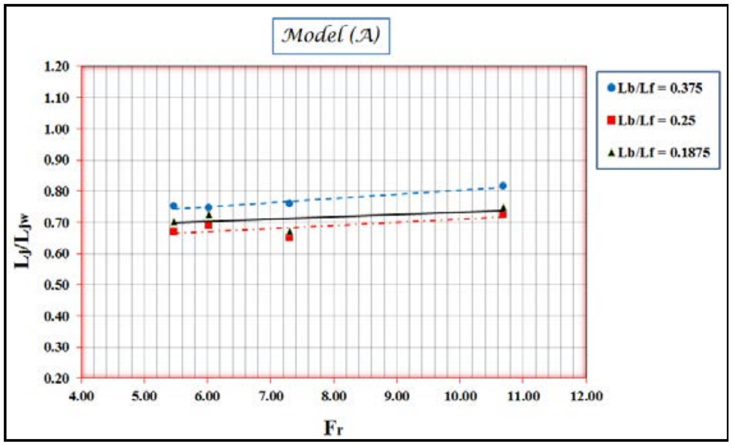


Figure (4): Relation between (Fr) and Lj/Ljw for Model A

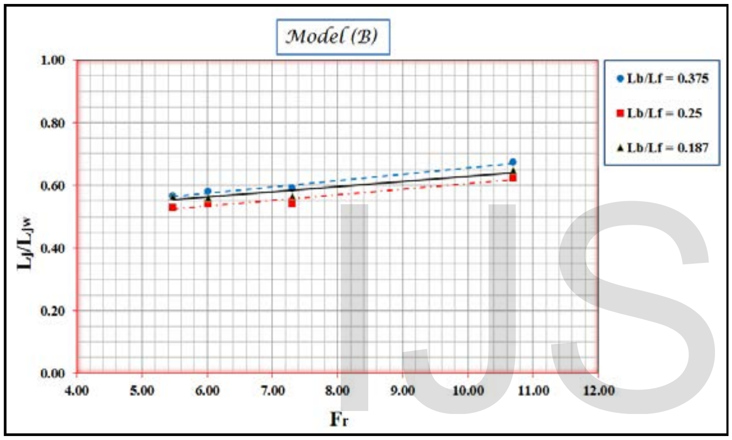


Figure (5): Relation between (F_r) and $L_j/L_{jw}$for Model B

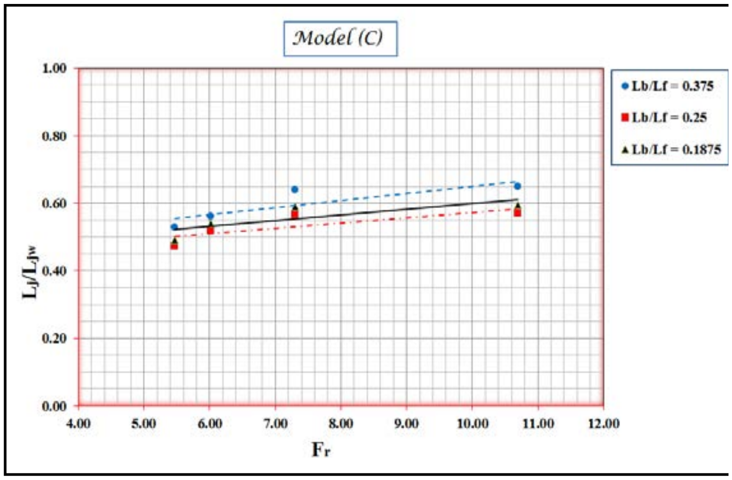


Figure (6): Relation between (Fr) and Lj/Ljw for Model C

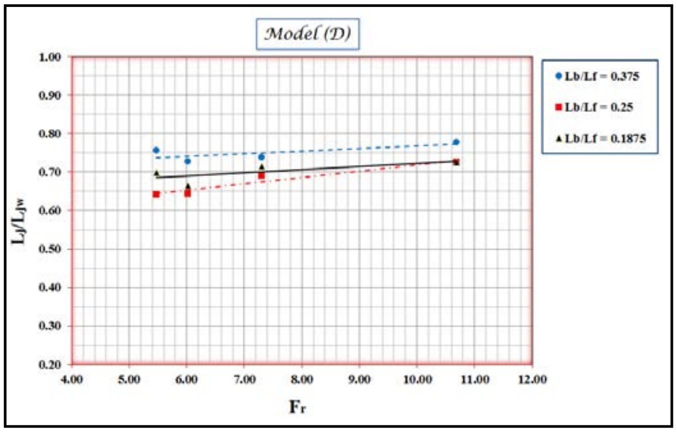


Figure (7): Relation between (Fr) and Lj/Ljw for Model D

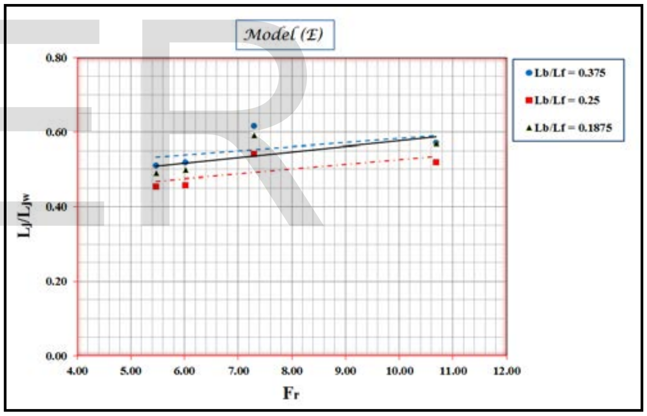


Figure (8): Relation between (F_r) and $L_j/L_{jw}$for Model E

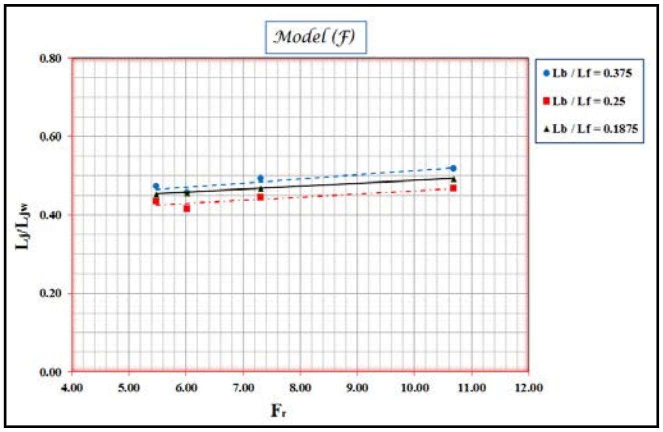


Figure (9): Relation between (F_r) and L_j/L_{jw} for Model F

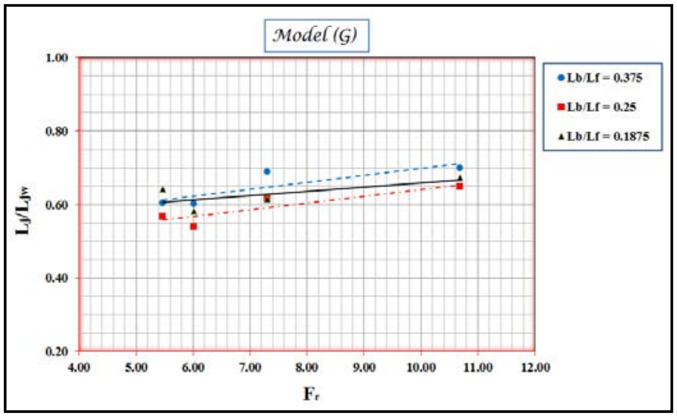


Figure (10): Relation between (F_r) and L_j/L_{jw} for Model G

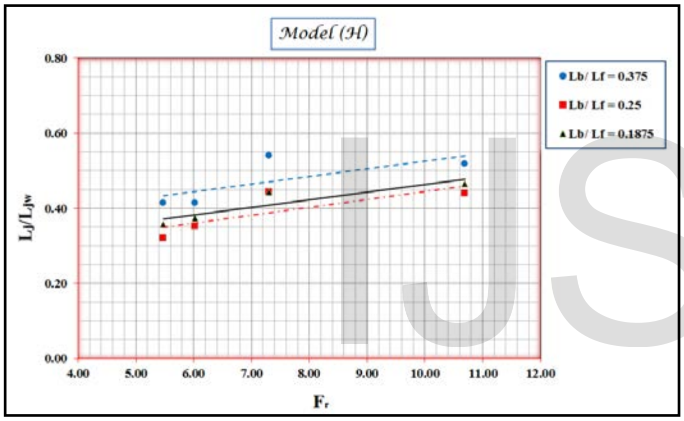


Figure (11): Relation between (F_r) and L_j/L_{jw} for Model H

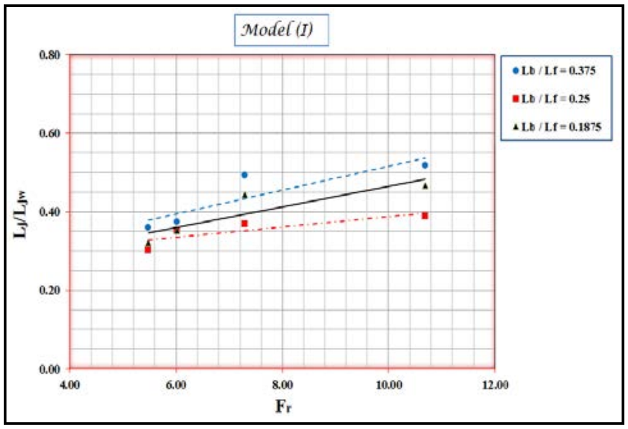


Figure (12): Relation between (F_r) and L_j/L_{jw} for Model I

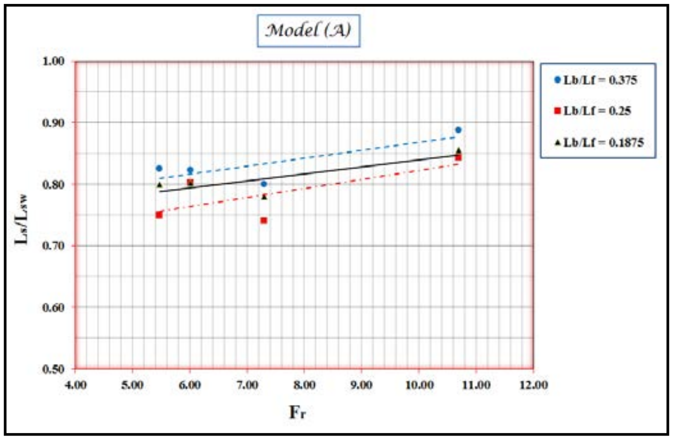


Figure (13): Relation between (F_r) and L_s/L_{sw} for Model A

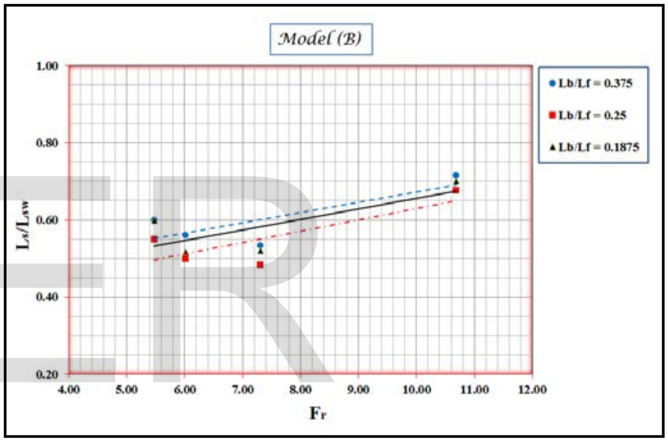


Figure (14): Relation between (F_r) and L_s/L_{sw} for Model B

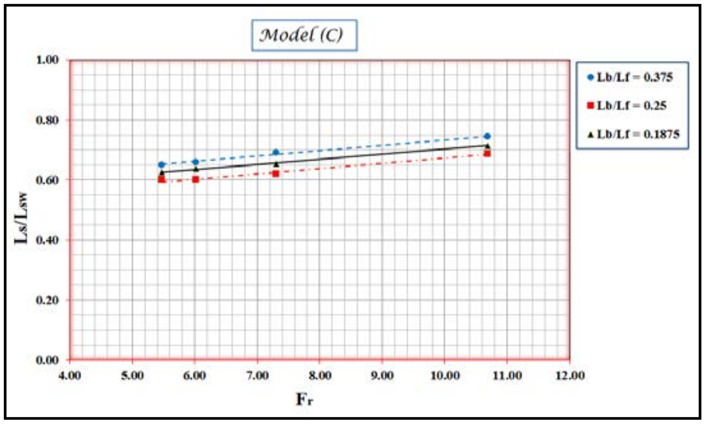


Figure (15): Relation between (F_r) and L_s/L_{sw} for Model C

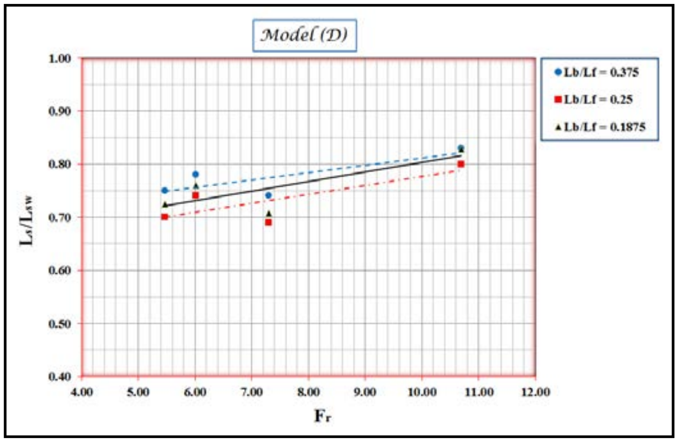


Figure (16): Relation between (F_r) and $L_s/L_{sw}$for Model D

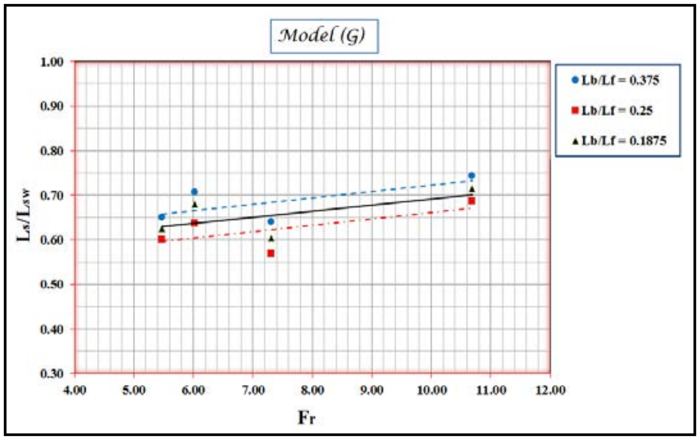


Figure (19): Relation between (F_r) and $L_s/L_{sw}$for Model G

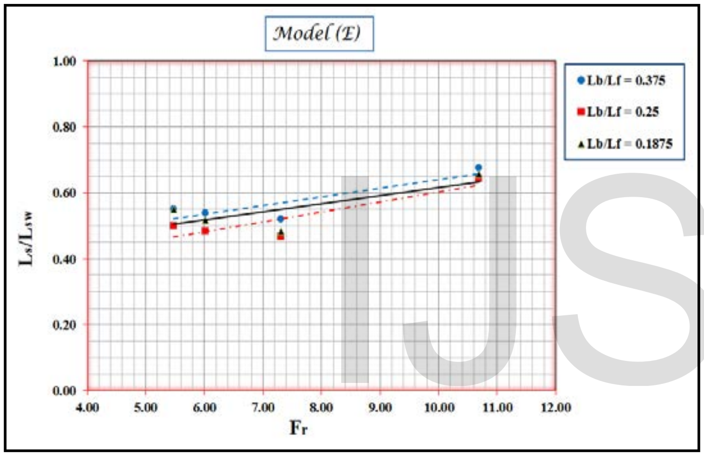


Figure (17): Relation between (F_r) and $L_s/L_{sw}$for Model E

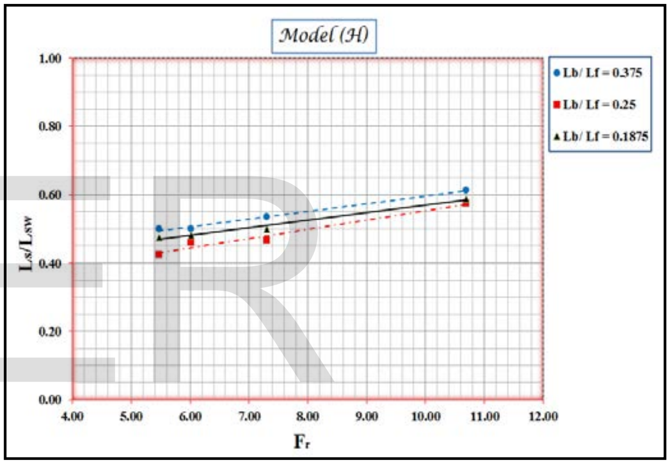


Figure (20): Relation between (F_r) and $L_s/L_{sw}$for Model H

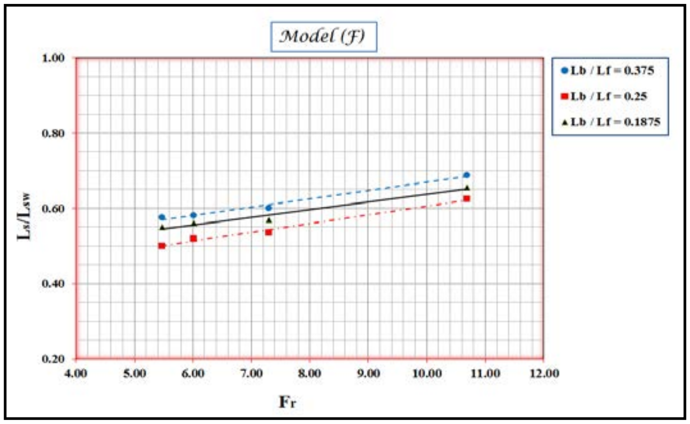


Figure (18): Relation between (F_r) and $L_s/L_{sw}$for Model F

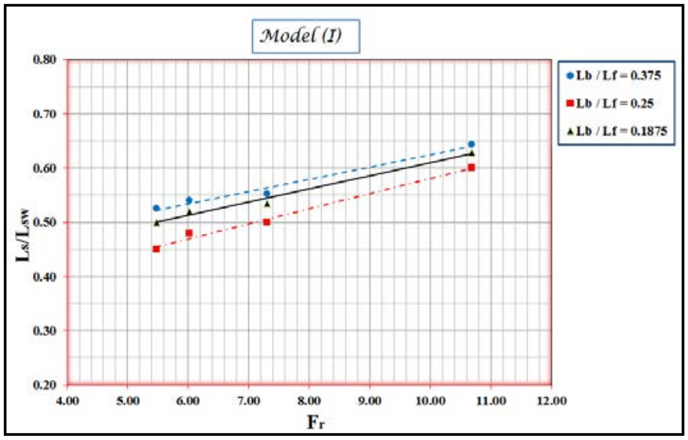


Figure (21) Relation between (F_r) and $L_s/L_{sw}$for Model I

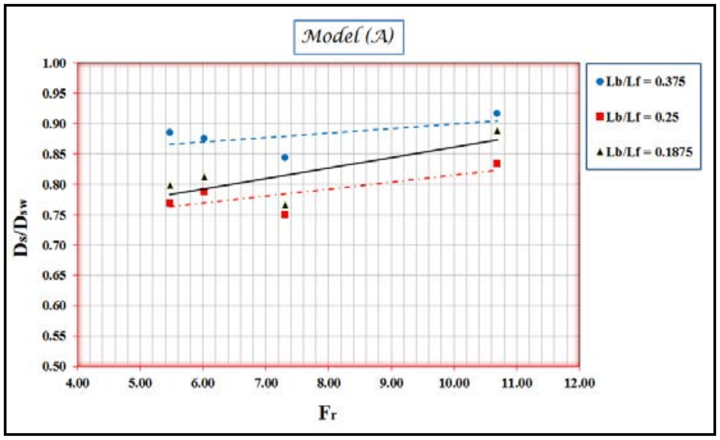


Figure (22): Relation between (F_r) and $D_s/D_{sw}$for Model

A

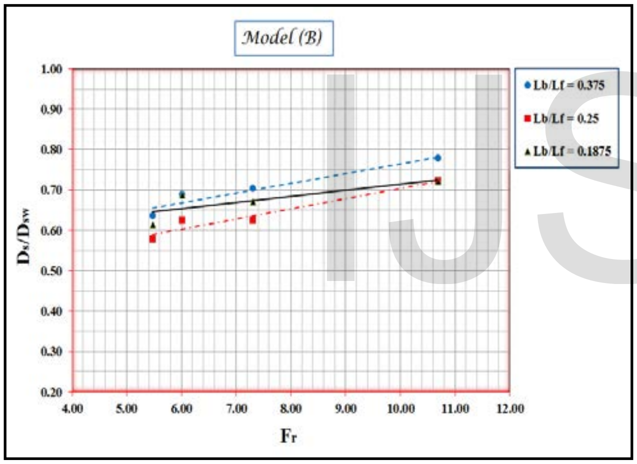


Figure (23): Relation between (F_r) and $D_s/D_{sw}$for Model

B

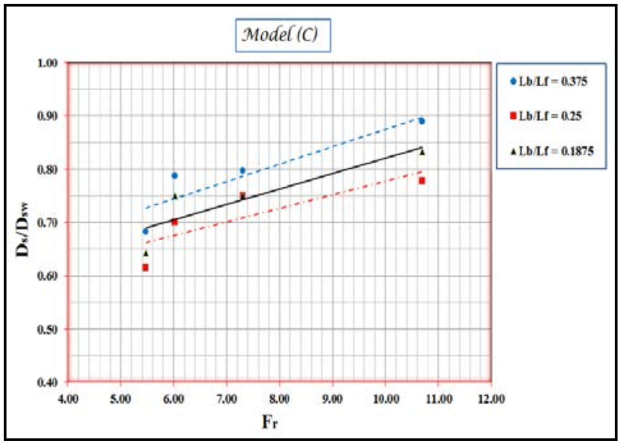


Figure (24): Relation between (F_r) and $D_s/D_{sw}$for Model

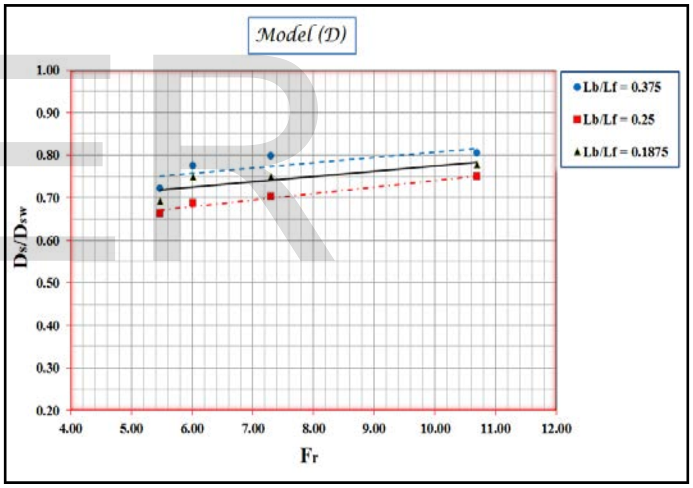


Figure (25) Relation between (F_r) and $D_s/D_{sw}$for Model D

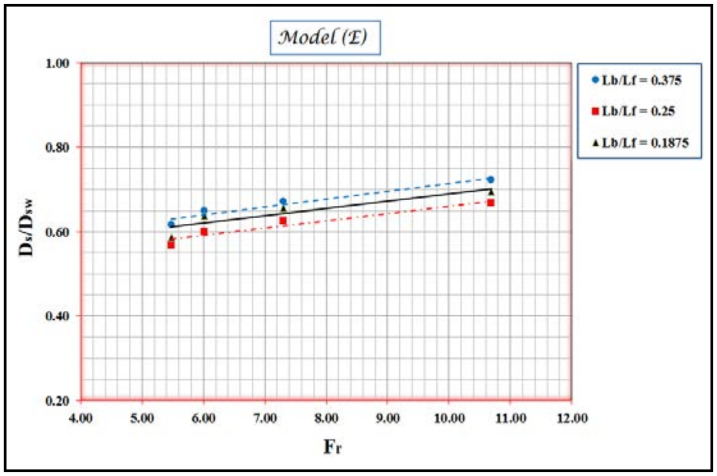


Figure (26) Relation between (F$_r$) and D$_s$/D$_{sw}$for Model E

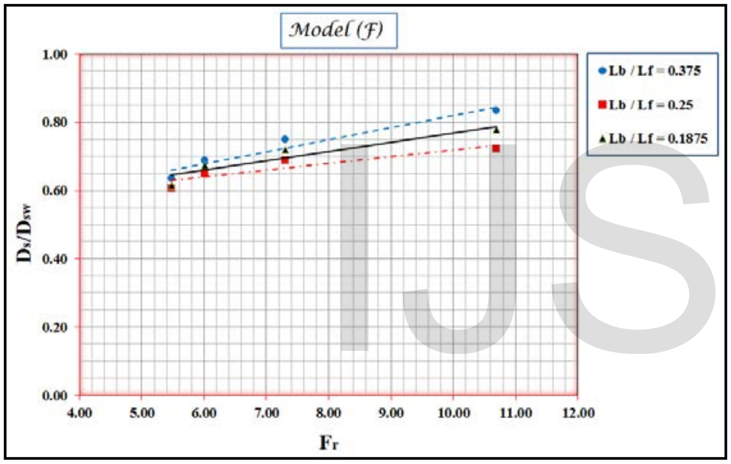


Figure (27): Relation between (F$_r$) and D$_s$/D$_{sw}$for Model

F

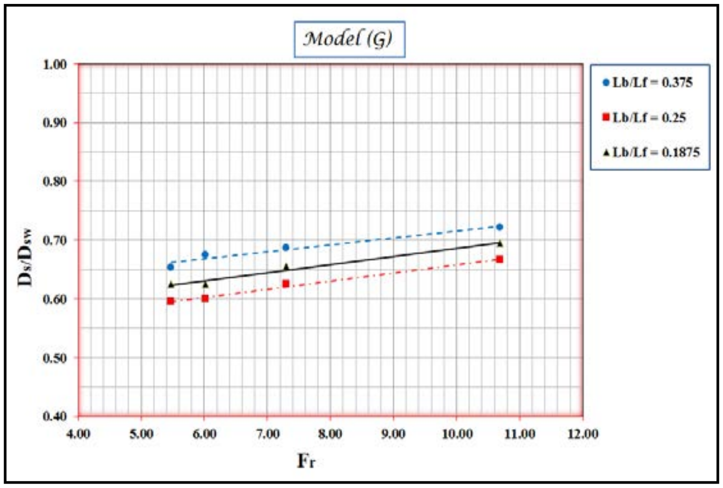


Figure (28): Relation between (F$_r$) and D$_s$/D$_{sw}$for ModelG

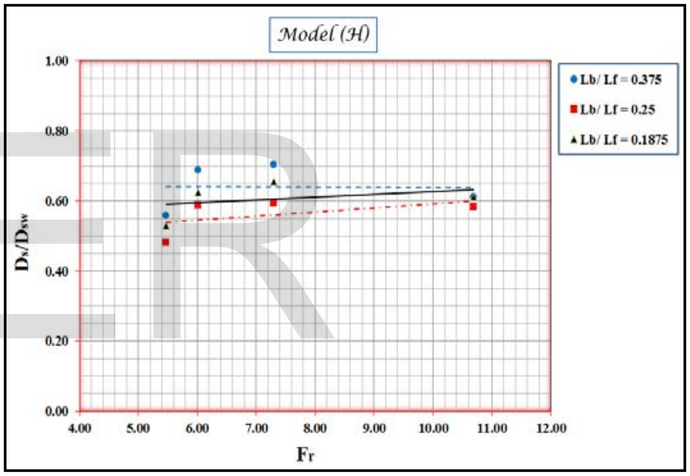


Figure (29): Relation between (F$_r$) and D$_s$/D$_{sw}$for ModelH

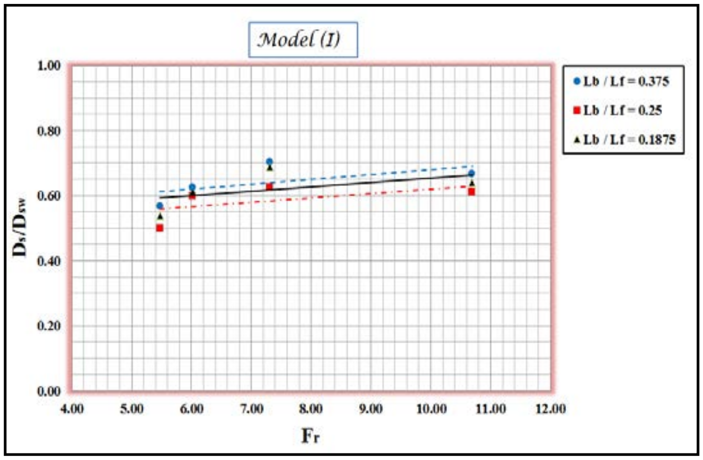


Figure (30): Relation between (F_r) and $D_s/D_{sw}$for Model I

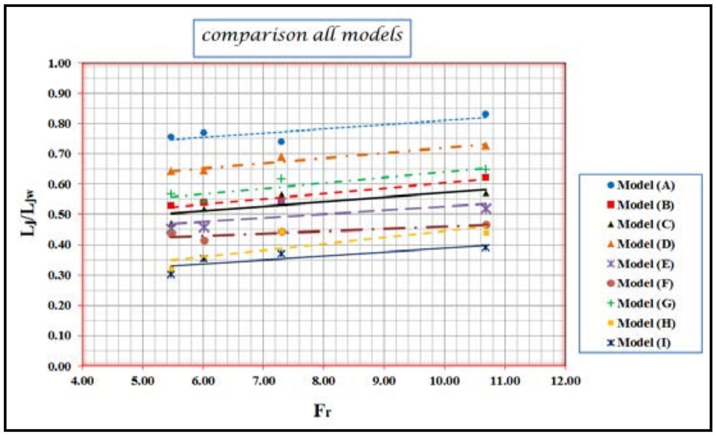


Figure (31): Relation between (F_r) and $L_j/L_{jw}$for all models

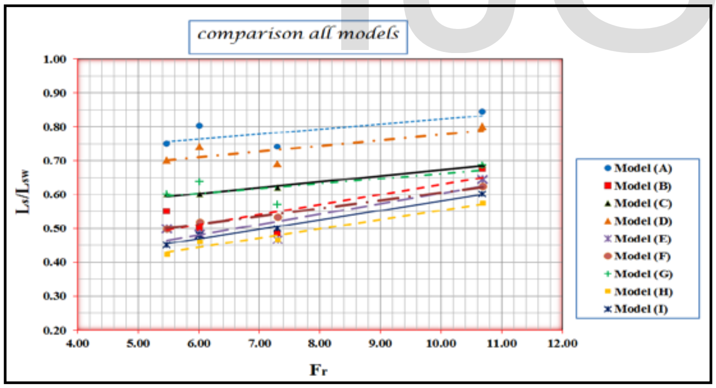
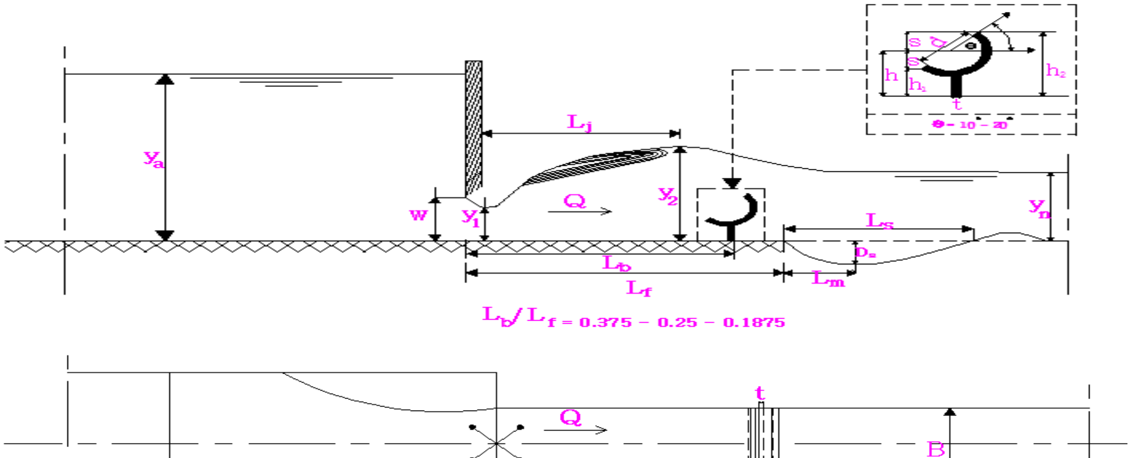
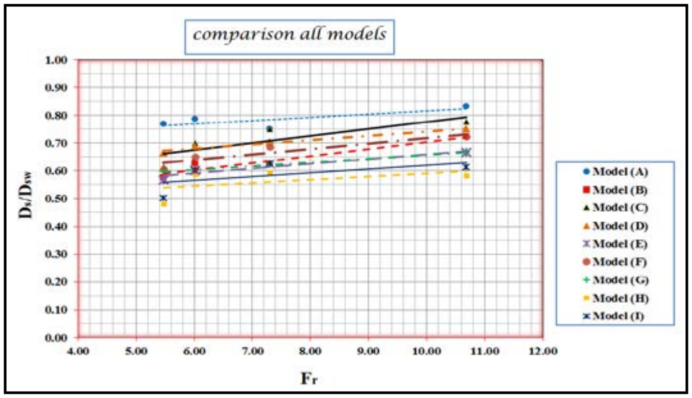
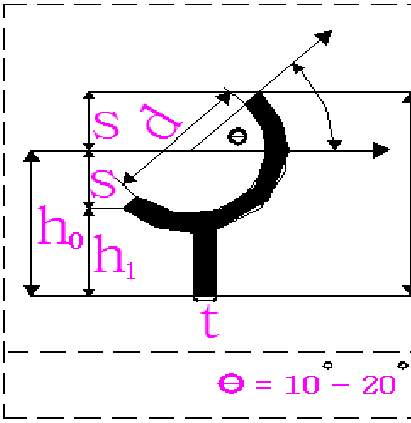


Figure (32): Relation between (Fr) and Ls/Lsw for all models

Figure (1) Definition sketch of ⋎-shaped sill and Hydraulic jump.







Figure(33): Relation between (F_r) and Ds/D_{sw} for all models

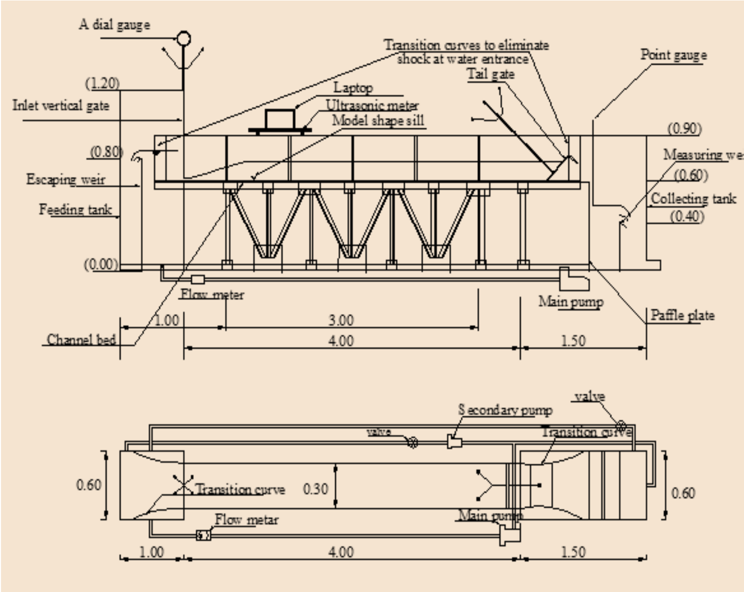


Figure (3) The experimental flume layout

Photo (1) The experimental flume

Figure (2) Definition sketch to the sill

Photo (2) View of measuring devices (Ultrasonic devices - multi spots).

Table (1) Definition of a crescent shaped (ϒ) sill models

Model	**d/h_o**	**Angel (Θ)**
A	0.67	0.00
B	0.85	0.00
C	1.00	0.00
D	0.67	10.00
E	0.85	10.00
F	1.00	10.00
G	0.67	20.00
H	0.85	20.00
I	1.00	20.00

Table (2) to the effect of innovative sill from all position

Model	length	percent length of jump	percent length of scour	percent of depth of scour
A	0.375	7 - 15%	12 - 21%	9 - 16%
	0.25	17 - 25%	16 - 26%	17 - 25%
	0.1875	14 - 23%	15 - 23%	12 - 23%
B	0.375	33 - 44%	28 - 44%	22 - 37%
	0.25	38 - 47%	33 - 51%	28 - 43%
	0.1875	35 - 44%	30 - 48%	28 - 39%
C	0.375	35 - 47%	26 - 35%	11 - 32%
	0.25	43 - 53%	31 - 40%	22 - 38%
	0.1875	40 - 51%	29 - 38%	17 - 36%
D	0.375	22 - 27%	17 - 26%	20 - 28%
	0.25	27 - 36%	20 - 31%	25 - 34%
	0.1875	27 - 34%	17 - 30%	22 - 31%
E	0.375	38 - 49%	33 - 48%	28 - 38%
	0.25	45 - 55%	36 - 53%	33 - 43%
	0.1875	43 - 51%	34 - 51%	30 - 41%
F	0.375	48 - 53%	31 - 43%	17 - 36%
	0.25	53 - 58%	37 - 50%	28 - 40%

	0.1875	50 - 55%	34 - 45%	22 - 38%
G	0.375	30 - 40%	26 - 36%	28 - 35%
	0.25	35 - 46%	31 - 43%	34 - 40%
	0.1875	33 - 42%	28 - 40%	30 - 38%
H	0.375	46 - 58%	39 - 50%	30 - 44%
	0.25	56 - 68%	43 - 57%	40 - 52%
	0.1875	53 - 64%	40 - 52%	34 - 47%
I	0.375	48 - 64%	36 - 48%	30 - 43%
	0.25	62 - 70%	40 - 55%	39 - 50%
	0.1875	53 - 68%	37 - 50%	31 - 46%

Table (3) A summary to the effect of the innovative sill form for best position

Model	Best relative floor length (L_b/L_f)	Best reduction percent length of jump	Best reduction percent depth of scour	Best reduction percent length of scour
A	0.25	17 - 25%	17 - 25%	16 - 26%
B	0.25	38 - 47%	28 - 43%	33 - 51%
C	0.25	43 - 53%	22 - 38%	31 - 40%
D	0.25	27 - 36%	25 - 34%	20 - 31%
E	0.25	45 - 55%	33 - 43%	36 - 53%
F	0.25	53 - 58%	28 - 40%	37 - 50%
G	0.25	35 - 46%	34 - 40%	31 - 43%
H	0.25	56 - 68%	40 - 52%	43 - 57%
I	0.25	62 - 70%	39 - 50%	40 - 55%

5. CONCLUSIONS AND RECOMMENDATIONS

Based on the above investigation phases, the concluded aspects were listed and are represented on table (2). In general, the conclusions are as follows:

- The innovative sill form possess a reasonable ability in the energy dissipation.
- The innovative sill form afforded a reasonable reduction in the scour length, depth and height of jump.

- The inclination of the upper crescent shaped (Y) sill increases the energy dissipation of the hydraulic jump.

- For jump length reduction, the optimum inclination choices angle is 20° and the optimum ratio is d/h_0 = 1.00 (i.e. Model (I) is the best model in reducing the jump length).

For scour length and scour depth reduction, the best inclination choices angle is 20° and the optimum ratio is The inclination of the upper crescent shaped (Y) sill increases the energy dissipation of the hydraulic jump.

- For jump length reduction, the optimum inclination choices angle is 20° and the optimum ratio is d/h_0 = 0.85. So (i.e. Model (H) is the best model that reduced scour length and scour depth).

- The bestenergydissipationratio was(d/h_0) = 1.00witha relative position of 0.25.

Based on the above, the following recommendations were foreseen and are given, as follows:

- Other innovative sill forms are to be investigated and tested.
- A wider range of diameter, Froude number and discharge are to be tested.
- The ratio between the lower part and upper part to be investigated and tested.
- A wider range of angle, Froude number and discharge are to be tested.

6. LIST OF REFERENCES

1. Abdouelatta N. “Hydraulic Jump Controlled By Jets” Unpublished Ph.D Thesis, Ain Shams Univeresity, Cairo, Egypt, 1990.

2. Ahmed Helmy “Efficiency of Using Unconventional Asymmetrical Sills Dissipaters Down Stream Hydraulic Structures” Unpublished M.Sc Thesis, Al-Azhar University, Cairo, Egypt, 2014.
3. Alikhani and others, “Hydraulic jump in stilling basin with vertical end sill” International journal of phesical science Vol. 5 (1), pp. 025-029, January, 2010.
4. Bejestan, M.S. and K. Neisi, “A new roughened bed hydraulic jump stilling basin“Asian J. Applied Sci., 2: 436-445, May 2009.
5. Bureau of Reclamation, Progress report II, Research study on stilling basins, energy dissipator, and associted appurtenances, Hydr. Lab Rep. Hyd-399, June, 1955.
6. F. Ayça VAROL “The Effect of Water Jet on the Hydraulic Jump” Thirteenth International Water Technology Conference, IWTC 13 2009, Hurghada, Egypt.
7. Hager, W. H. and Sinniger, R, “Flow characteristis of the hydrauluc jump in a stilling basin with an abrupt bottom rise” , J. Hydraulic Research, Vol23, No.2,1985, pp.101 – 113, Discussion Vol 25, No.3, 1986, pp. 207 – 215.
8. Hagar, W.H., (1993), "T-jump in abruptly expanding channel", journal of hydraulic research. Vol. 31. No. I.
9. Mostafa Ali (2008): “Using Aprons Of Formed Surfaces As Energy Dissipaters Down Stream Hydraulic Structures". Ph.D. Thesis. Al-Azhar University, Faculty Of Engineering, Cairo, Egypt. 2008.
10. Osama A. (2008): “Control of hydraulic jump by curved sill " M.Sc. Thesis. Al-Azhar University, Faculty Of Engineering, Cairo, Egypt. 2008.

11. Pillai, A. Goel, and A. K. Dubey, “Hydraulic Jump Type Stilling Basin for Low Froude Number” Jour. Of Hyd. Eng, AsCE, Vol. 115, No. 7, July 1989.
12. Razavan, E. “ L Influence de la haute turbulence sur l’ entrainement des alluvions” 14th Congress of IAHR, Paris, Vol. 3. No. paper C3 1971.
13. Sholichin and Shatira ” Development of drop number performance for estimate hydraulic jump on vertical and sloped drop structures” International journalof the phisical science. Vol 5(11), pp.168. 2010.
14. Tople, S. K. P.; Poey, P. D. and Ranga Raju, K. G. : "Hydraulic Jump Under the Influence of Two-Dimensional Cross Jets". J. Inst. Eng. (India) Part CI 6, Vol. 66, May 1986, pp. 277-83.
15. Walid M. Abd Elgalil (2006): “Effect of Side Flow on The Energy Down Stream Sluice Gate” unpublished Ph.D Thesis, Al-Azhar University, Cairo, Egypt, 2006.
16. YousriZaghlool“Flow Characteristics in the Neighbourhood of Concave Obstructs" M.Sc.Thesis. Al-Azhar Universty Faculty of Engineering, Ciro, Egypt. 1985