ASSESSING THE IMPACT OF SEMI-CIRCULAR BAFFLE BLOCKS ON SCOUR DOWNSTREAM SLUICE GATES

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ABSTRACT

In the framework of expanding the arable land by constructing mega hydraulic structures that might be subjected to failure due to scour that implies the extension of the aprons, which adds extra costs. Accordingly, this research was originated with the impartial of assessing the impact of semi-circular baffle blocks on scour downstream sluice gates, in terms of length and depth. 40 experiments were carried out in Hydraulic Laboratory in AlAzhar University, where a flume equipped with measuring devices was set up. Three ratios of baffle blocks diameter to height "D_b/H_b" and three ratios of their location from the gate to the length of the apron downstream (D.S) the gate "L_b/L_f" were considered. Runs were conducted without semi-circular baffle blocks, as a reference, for comparison purposes. Measurements were undertaken; represented on graphs and analyzed. Conclusions were deduced and recommendations were suggested. The research results highlighted that implementing $D_b / H_b = 0.78$, reduced scour length so as depth, at "$L_b / L_f = 0.37$".

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تقييم تأثير البلوكات النصف الدائرية على النحر خلف البوابات

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الملخص

في إطار توسيع رقعة الأراضي الصالحة للزراعة، من خلال إنشاء المنشآت الهيدروليكية الضخمة التى قد يهددها النحر وبالتالى يجب زياده طول الفرش مما يؤدى إلى زيادة التكلفة. وبالتبعية بدأ هذا البحث بهدف تقييم تأثير البلوكات النصف دائرية على النحر، حيث تم إجراء ٤٠ تجربة في معمل الهيدروليكا بجامعة الأزهر تحت تأثير تغيير نسبة "أقطار البلوكات إلى ارتفاعاتها D_b / H_b"، ثلاث مرات، وكذا تغيير نسبة "بعدها عن البوابة الى طول الفرش خلف البوابةL_b / L_f"، ثلاث مرات. كما تم إجراء نفس التجارب فى حالة عدم وجود البلوكات النصف دائرية ، لتستخدم كقيم مرجعية لأغراض المقارنة. وتم أخذ القياسات؛ وتمثيلها بيانياً وبتحليلها تم استنباط الاستنتاجات واقتراح التوصيات. وقد أوضحت نتائج البحث أن النسبة "$D_b / H_b = 0.78$"، حققت انخفاضاً ملحوظاً فى طول النحر وعمقه ، وذلك فى حالة تواجد البلوكات عند "$L_b / L_f = 0.37$".

1. INTRODUCTION

Water structures are important structures that collapse if cracked causing unexpected disasters. Accordingly, this research was initiated with the objective of assessing the impact of semi-circular baffle blocks on scour downstream sluice gates, in terms of length and depth.

Many studies investigated the factors that affect such structures, in terms of scour at their downstream, as scour implies the extension of their aprons, which adds extra costs to the structure. Among them for example is **U.S. Bureau of reclamation (10)** who conducted measurements to the hydraulic jump length at Froude number 2-20. Their results flagged out that the ratio between the jump length to height is 6.9. In addition, **Aboulatta, N., (2)** investigated, analytically and experimentally, apron jets in radial basins for free jumps, where she designated the bed jet influence on free jump characteristics of the free hydraulic jump. Likewise, **El-Masry (4)** implemented single, double, and fully baffled aprons with different baffle block shapes. His results signposted that fully baffled apron proved its applicability. Similarly, **El- Enany et al. (5)** tested three lines of baffle blocks at different angles, where their results indicated

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that baffle block shape, dimension and arrangement affect the scour hole dimensions. Accordingly, not any solution is applicable to any condition. In contrast, **Ali, M., (8)** investigated the efficiency of parabolic sill downstream hydraulic structures. Likewise, **Alashry, O., (9)** investigated the combination of vertical so as horizontal concavities on scour. His results reflected that at X = 1.67, reasonable y_2/y_1 values were obtained. Moreover, **Abdelhaleem, H., (1)** studied the optimum design of staggered concrete blocks downstream regulators, where she studied the effect of flow characteristics on the end sill. Her results indicated that baffle location at 30 to 50% of basin length provided the least scour. **Helmy, A., (3)** investigated the impact of Y-sill on hydraulic jumps, where he studied three angles (i.e. 45º, 30º and 15º). His results indicated that angle 30º at $L_b/L_f = 0.22$ provided the least scour depth. **Javad, F. and Hossein, Kh., (7)** studied the local scour downstream of adverse stilling basins where a sub-merged wall jet issued from a sluice gate. Experiments were conducted in a wide range of Froude numbers, grain sizes, tail water depths, and stilling basin slopes The results showed that the scour profiles at any bed slope follow shape similarity. Lately, **Ibrahim M. M., (6)** studied the impacts of block shapes on the flow pattern downstream a radial gate. Forty-five (45) exploratory runs were done. Four different states of baffle blocks were considered, notwithstanding an instance of level floor without blocks was incorporated into the test program to evaluate the impact of utilizing the blocks. Each case was tried with various flow conditions; three unique discharges and three diverse tail water depths were utilized. Results were investigated and graphically exhibited. The tests demonstrated that the blocks exhibited a high proficiency in limiting the detached impact of the flow pattern downstream the gate.

2. PARAMETRIC INVESTIGATION

A non-dimensional analysis was conducted to correlate the variables contributing in the problem in hand for a single line of baffles, where their geometry are defined on figure (1) and table (1).

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Relationships were obtained between jump length (L_j), Froude number (F_r), relative scour depth (D_s / D_{sw}) and scour length to depth (L_s / L_{sw}), where the depths upstream and downstream of the jump were denoted as Y_1 and Y_2, respectively.

ΔY is the height of the hydraulic jump, as follows:

$$\Delta Y = (Y_2 - Y_1) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (1)}$$

Length of jump is denoted by L_j, as follows:

$$L_j = 6.9 \Delta Y \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (2)}$$

(y_2) is given in terms of (y_1), as follows:

$$y_2 = -\frac{y_1}{2} + \sqrt{\frac{2 v_1^2 y_1}{g} + \frac{y_1^2}{4}} \quad \dots\dots\dots\dots\dots \text{ (3)}$$

Froude number (F_r) is as follows:

$$F_r = \frac{v}{\sqrt{gy}} \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (4)}$$

If Froude number (Fr) is introduced to equation (3), the following is obtained:

$$y_2 = \frac{y_1}{2}(\sqrt{1 + 8 F_r^2} - 1) \quad \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots \text{ (5)}$$
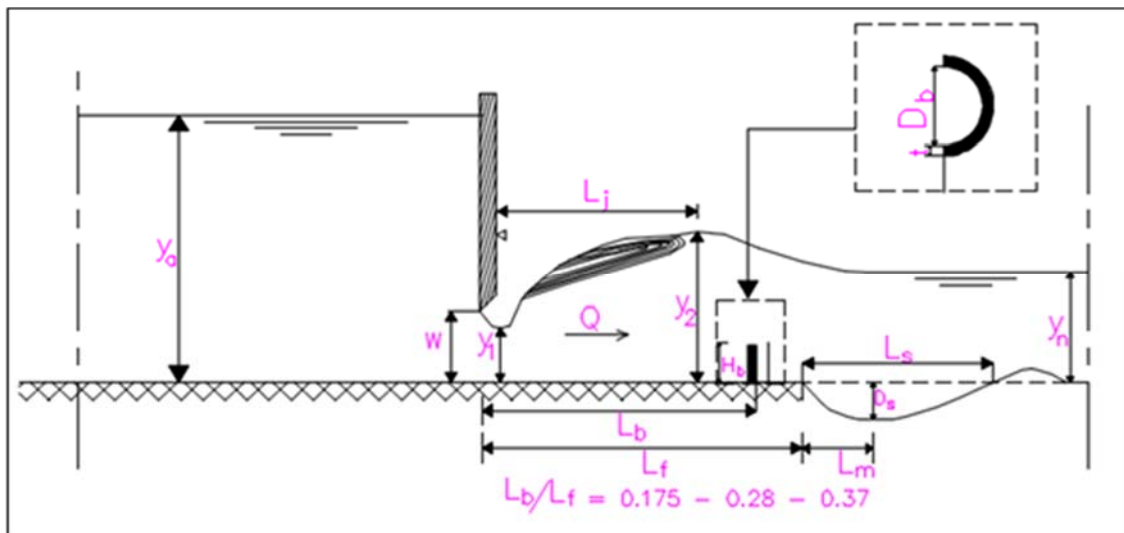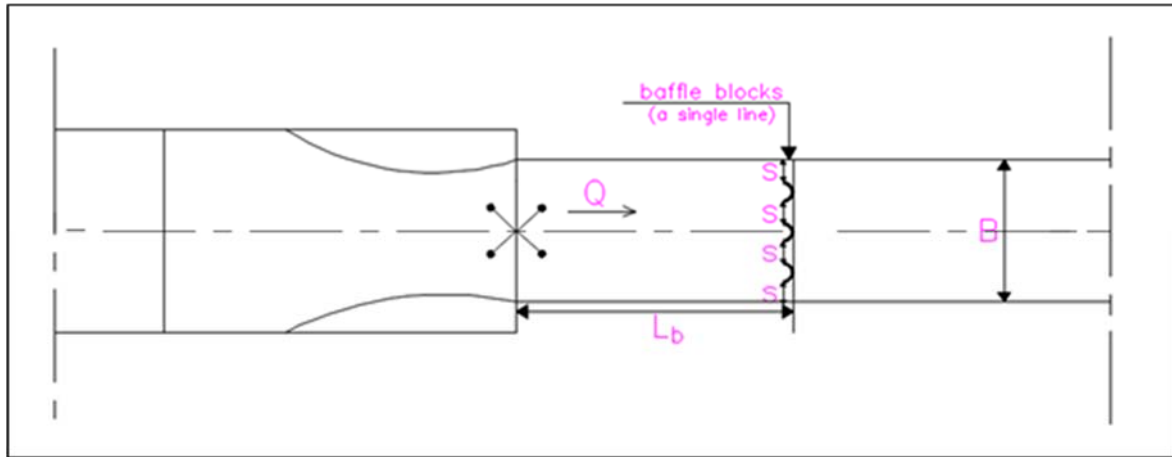
Figure (1) Geometrical parameters in elevation and plan

Table (1) Variables units and dimensions

Symbol	Definition	Units	Dimension
	Geometrical properties		
L_f	Length of apron downstream the gate.	m	L
L_b	Distance from the control structure to the first sill.	m	L
L_j	Length of the hydraulic jump.	m	L
L_{jw}	Length of the hydraulic jump (case without sill).	m	L
t	Thickness of sill.	m	L
s	Distance between baffle blocks.	m	L
D_b	Diameter of the sill.	m	L
H_b	Height of the sill.	m	L
B	Width of channel.	m	L
W	Opening the gate.	m	L
y_1	Depth at beginning of hydraulic jump.	m	L
y_2	Depth at end of hydraulic jump.	m	L
y_n	Tail water depth.	m	L
	Flow properties		
V_1	Velocity at beginning jump.	m/sec	LT^{-1}
V_2	Velocity at end jump.	m/sec	LT^{-1}
Q	Discharge of the channel.	m ^{3}/ sec	$L^3 T^{-1}$
g	Gravitational acceleration.	m/sec^2	LT^2
	Fluid properties		
ρ	Mass density of fluid.	kg_m/m^3	ML^{-3}
μ	Dynamic viscosity.	$kg_m/m.sec$	$ML^{-1}T^{-1}$
	Soil properties		
S.G	Soil Specific gravity.	-------	Dimensionless
D_{50}	Mean diameter of sediments.	m	L
Ø	Internal friction angel of soil.	-------	Dimensionless
	Scour properties		
Ds	Maximum scour depth.	m	L
D_{sw}	Maximum scour depth (case without sill).	m	L

L_s	Length of scour hole.	m	L
L_{sw}	Length of scour hole (case without sill).	m	L
L_m	Position of maximum scour depth.	m	L

S.G could be cancelled. This provides

$$\Phi = f(L_f, L_b, L_j, L_{jw}, t, H_b, B, D_b, y_1, y_n, Q, \rho, g, \mu, S.G, \emptyset, D_s, D_{sw}, L_s, L_{sw}, L_m, s, v_1, v_2)$$

…………..… (1)

 Where:

B : channel width

Q : discharge

ρ : density of fluid

g : acceleration due to gravity

μ : dynamic viscosity

S.G : specific density

 Ø : selected soil diameter

The parameters Ø and S.G could be deleted from the variables.

 According to Buckingham π-theorem, the general form of relationship between these variables may be written as follows:

$$\phi = \left(\frac{L_f}{B}, \frac{L_b}{B}, \frac{L_j}{B}, \frac{L_{jw}}{B}, \frac{t}{B}, \frac{H_b}{B}, \frac{D_b}{B}, \frac{y_1}{B}, \frac{y_n}{B}, \frac{Q^2}{B^5 g}, \frac{\rho Q}{B \mu}, \frac{D_s}{B}, \frac{D_{sw}}{B}, \frac{L_s}{B}, \frac{L_{sw}}{B}, \frac{L_m}{B}, \frac{s}{B}, \frac{V_1}{(gB)^{0.5}}, \frac{V_2}{(gB)^{0.5}} \right)$$

…………..... (2)

Taking the properties of π-terms into account, the following relationship was obtained:

$$\phi_1 = \left(\frac{L_b}{L_f}, \frac{L_j}{L_{jw}}, \frac{t}{s}, \frac{D_b}{H_b}, \frac{h_1}{h_2}, \frac{y_2}{y_1}, \frac{V_1}{V_2}, F_r, R_n, \frac{D_{50}}{B}, \frac{D_s}{D_{sw}}, \frac{L_s}{L_{sw}}, \frac{L_m}{y_n} \right)$$ …….........… (3)

Where:

L_b / L_f : relative apron length

L_j / L_{jw} : relative hydraulic jump length

t / s : ratio between baffle blocks thickness to the distance between them

D_b/H_b : ratio between diameter and height of baffle block

y_2/y_1 : relative conjugate depth

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v_1 / v_2 : relative conjugate velocity

F_r : Froude number

R_n : Reynolds number

D_{50} / B : ratio between Mean diameter of sediments and width of channel

D_s / D_{sw} : relative scour depth

L_s / L_{sw} : relative scour length

L_m / y_n is the ratio between position maximum depth and tail water depth.

Finally, the function will be as follows:

$$F_r = \phi\left(\frac{L_b}{L_f}, \frac{L_j}{L_{jw}}, \frac{t}{s}, \frac{D_b}{H_b}, \frac{y_2}{y_1}, \frac{V_1}{V_2}, \frac{D_{50}}{B}, \frac{D_s}{D_{sw}}, \frac{L_s}{L_{sw}}, \frac{L_m}{y_n} \right) \qquad \ldots\ldots\ldots\ldots\ldots\ldots. (4)$$

3. EXPERIMENTAL INVESTIGATION

Forty tests were conducted. The experimental investigation was carried out in the Hydraulic Laboratory of Al- Azhar University, where a flume was set up an equipped with measuring devices. The flume cross section is supported by 30×30 cm rectangular steel frame with visible clear polycarbonate sides. Its length 4.0 m, figures (2) and (3). The ratio D_b/H_b of the baffle blocks was varied to be 0.62, 0.78 and 1.00, while their width (t) was kept constant to be 0.30 cm. Their placement location was varied 3 times L_b / L_f was 0.175, 0.28 and 0.37. In addition, 5 discharges were considered.

The baffle blocks were fitted at different locations, relative to the gate. The bed material was accurately leveled and checked by a water gauge. The hydraulic jump was formed under free flow downstream the gate and stabilized, after which the measurements were undertaken; observations were recognized and photos were captured.

The experimental procedure progressed, as follows:

- The required discharge was passed, where a measuring weir (i.e. pre-calibrated in the hydraulic laboratory, $Q = 0.371 H^{1.5}$) was implemented; figure (4).
- The sequent depth y_2 was measured.
- Jump length L_j was measured from the jump edge to the top roller of the jump.

- The longitudinal scour whole profile was measured at intervals of 5 cm by means the gauge and Ultrasonic.

- The velocity distribution downstream the elements and the normal water depth were measured.
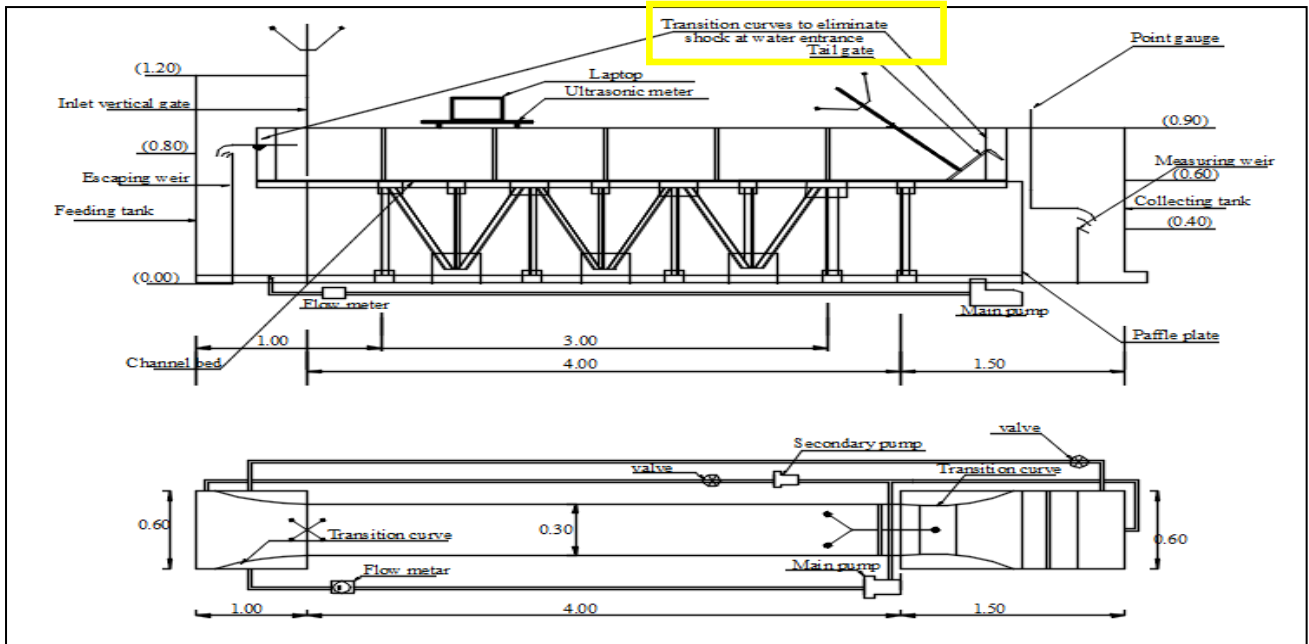

Figure (2) the experimental flume layout

Figure (3) The experimental flume with measuring devices
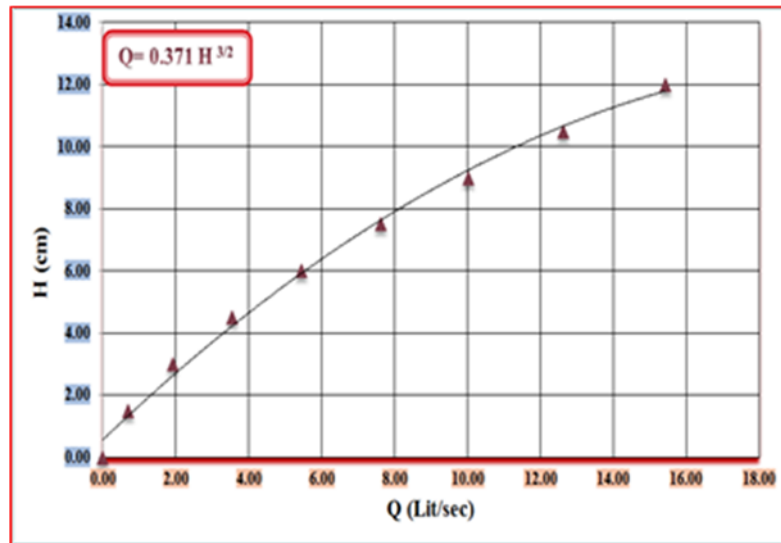
(Ultrasonic devices - multi spots)

Figure (4) Weir pre-calibration

4. RESULTS ANALYSIS AND DISCUSSION

The measurements were analyzed, from which table (2) is provided to summarize the obtained results. In addition, self-explanatory graphs were produced and are presented on figures (5) to (13).

4.a. ANALYZING AND DISCUSSING L_j/L_{jw} RESULTS

Figures (5), (6) and (7) related Froude number (F_r) to L_j/L_{jw}, from which, the following were designated:

- L_j/L_{jw} is directly proportional to F_r.
- For all Froude number (F_r) values, the reasonable position for the baffle blocks was at L_b/L_f =0.37, where at (D_b/H_b) of 1.00, 0.78 and 0.62, the jump length was reduced 33 to 45%, 43 to 55% and 17 to 28%, respectively.
- This indicated that the appropriate position to the sills at L_b/L_f =0.37 at (D_b/H_b) =0.78, as it reduced the jump length by 55%.

4.b. ANALYZING AND DISCUSSING SCOUR LENGTH RESULTS

Figures (8), (9) and (10) related Froude numbers (F_r) to L_s/L_{sw}, from which the following were highlighted:

- L_s/L_{sw} is directly proportion to Froude number (F_r).
- The appropriate sill position is at $L_b/L_f = 0.37$, where at (D_b/H_b) of 1.00, 0.78 and 0.62, the scour length was reduced by 28 to 38%, 31 to 45% and 25 to 28%, respectively.
- This indicated that the appropriate position to the sill is at $L_b/L_f = 0.37$ at (D_b/H_b) =0.78, as it reduced the scour length by 45%.

4.c. ANALYZING AND DISCUSSING SCOUR DEPTH RESULTS

Figures (11), (12) and (13) were related Froude number (F_r) to L_s/L_{sw}, from which the following were highlighted:

- D_s/D_{sw} is directly proportion to Froude number (F_r)
- The appropriate sill position is at $L_b/L_f = 0.37$, where at (D_b/H_b) of 1.00, 0.78 and 0.62, the scour depth was reduced by 30 to 36%, 38 to 42% and 14 to 26%, respectively.
- This indicated that the appropriate position to the sill is at $L_b/L_f = 0.37$ at (D_b/H_b) =0.78, as it reduced the scour depth by 42%.

Table (2) Semi-circular baffle block results

Relative (D_b/H_b)	Length of jump at $L_b/L_f = 0.37$	Scour length at $L_b/L_f = 0.37$	Scour depth $L_b/L_f = 0.37$
1.00	33 - 45%	28 - 38%	30 - 36%
0.78	43 - 55%	31 - 45%	38 - 42%
0.62	17 - 28%	25 - 28%	17 - 25%
Min/max	17 % - 55%	25% -51%	14% - 26%

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5. CONCLUSIONS AND RECOMMENDATIONS

Based on the above, the following are the deduced conclusions:

- Semi-circular baffle blocks form possesses a reasonable energy dissipation.
- Semi-circular baffle blocks afforded a reasonable reduction in scour length and depth so as jump height.
- The ratio $(D_b/H_b) = 0.78$ at L_b/L_f 0.37 provided reasonable results.

Based on the above, the following recommendations were suggested:

- Double line of semi-circular baffle blocks is to be investigated.
- Wider ranges of diameters so as Froude number and discharge are to be investigated.

5. REFERENCES

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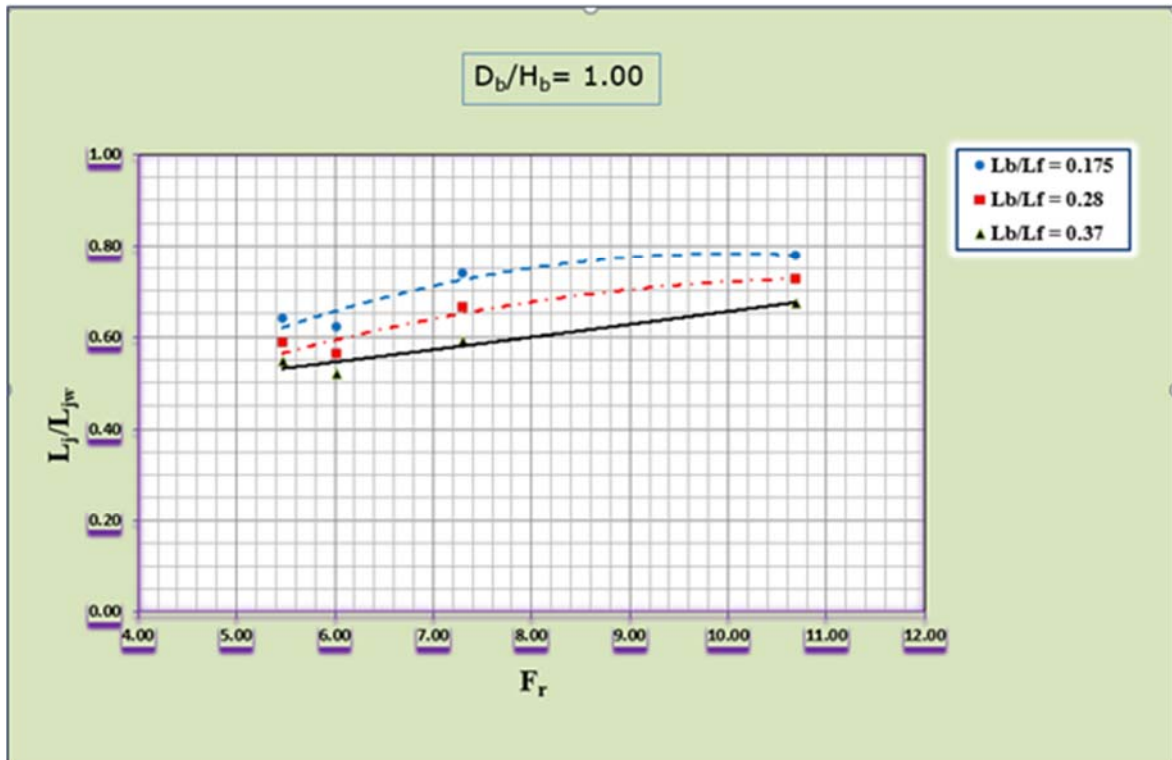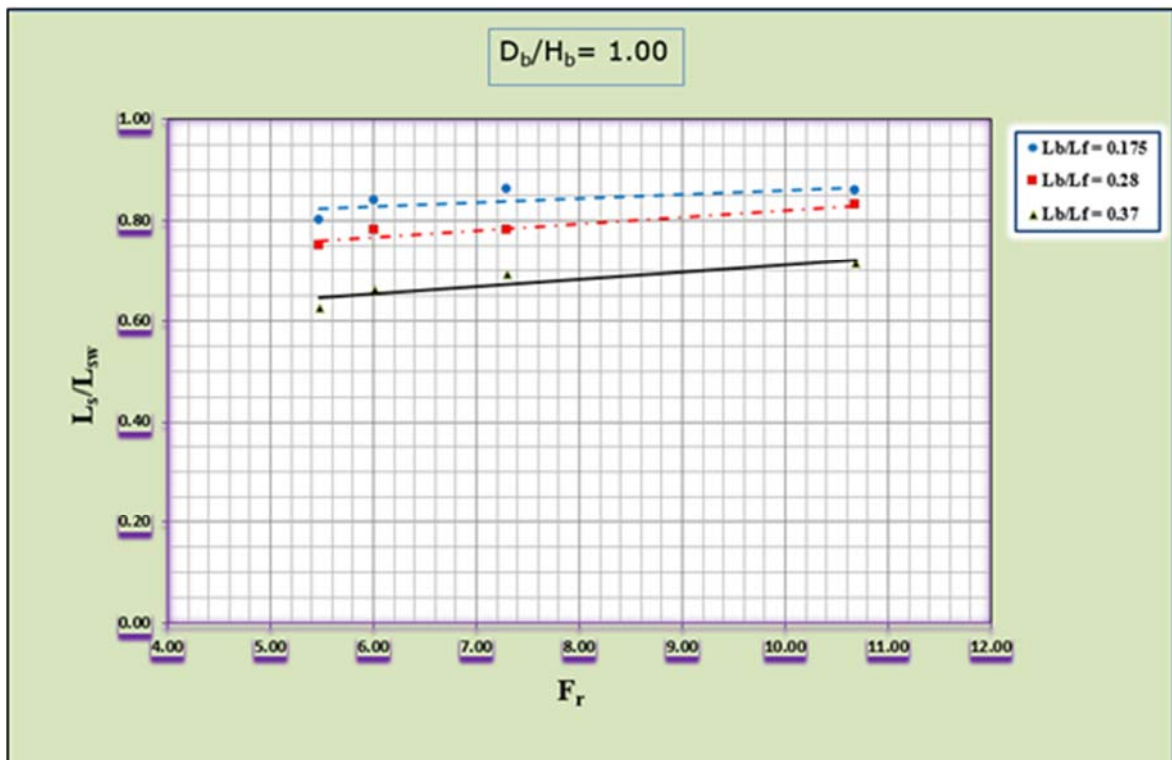
Figure (5) Relation between (F_r) and L_j/L_{jw} for D_b/H_b = 1.00
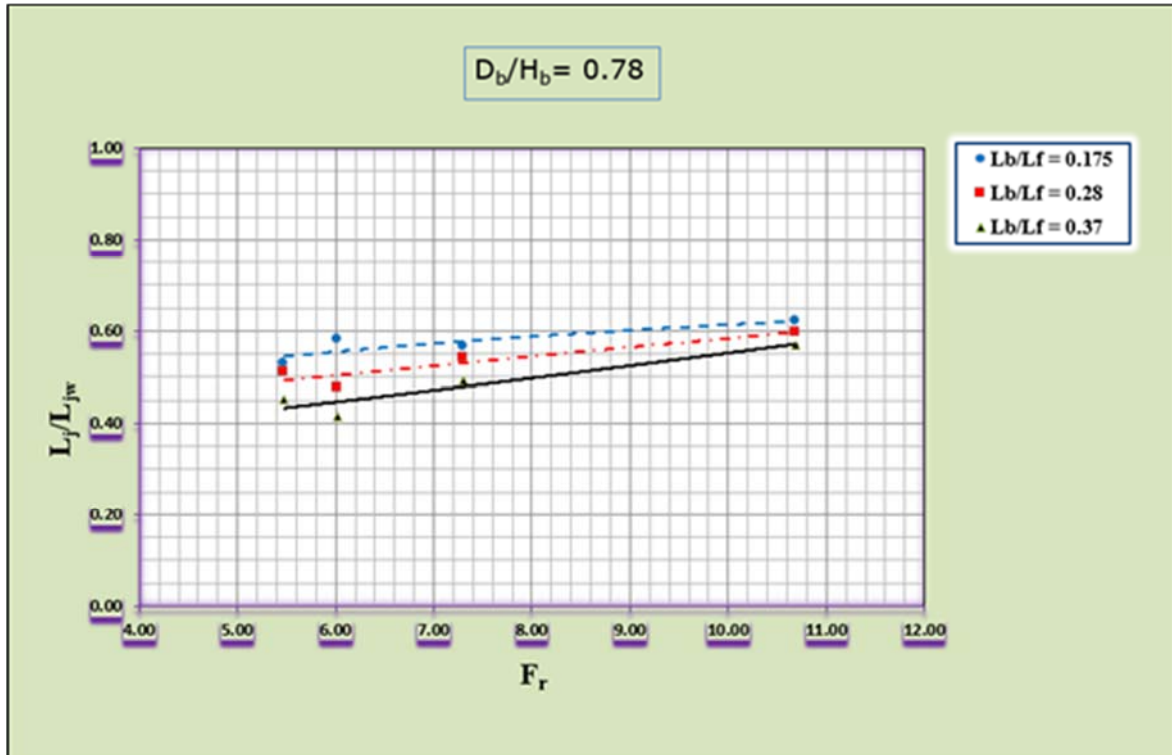
Figure (6) Relation between (F_r) and L_j/L_{jw} for D_b/H_b = 0.78
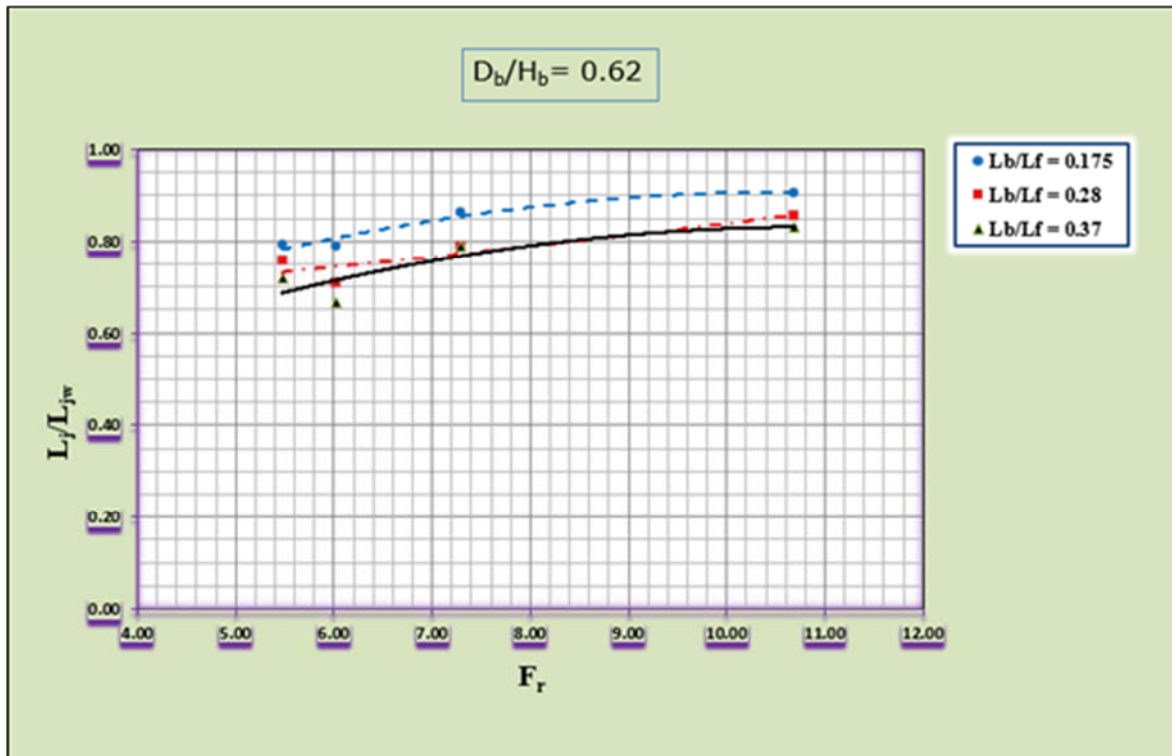
Figure (7) Relation between (F_r) and L_j/L_{jw} for $D_b/H_b = 0.62$

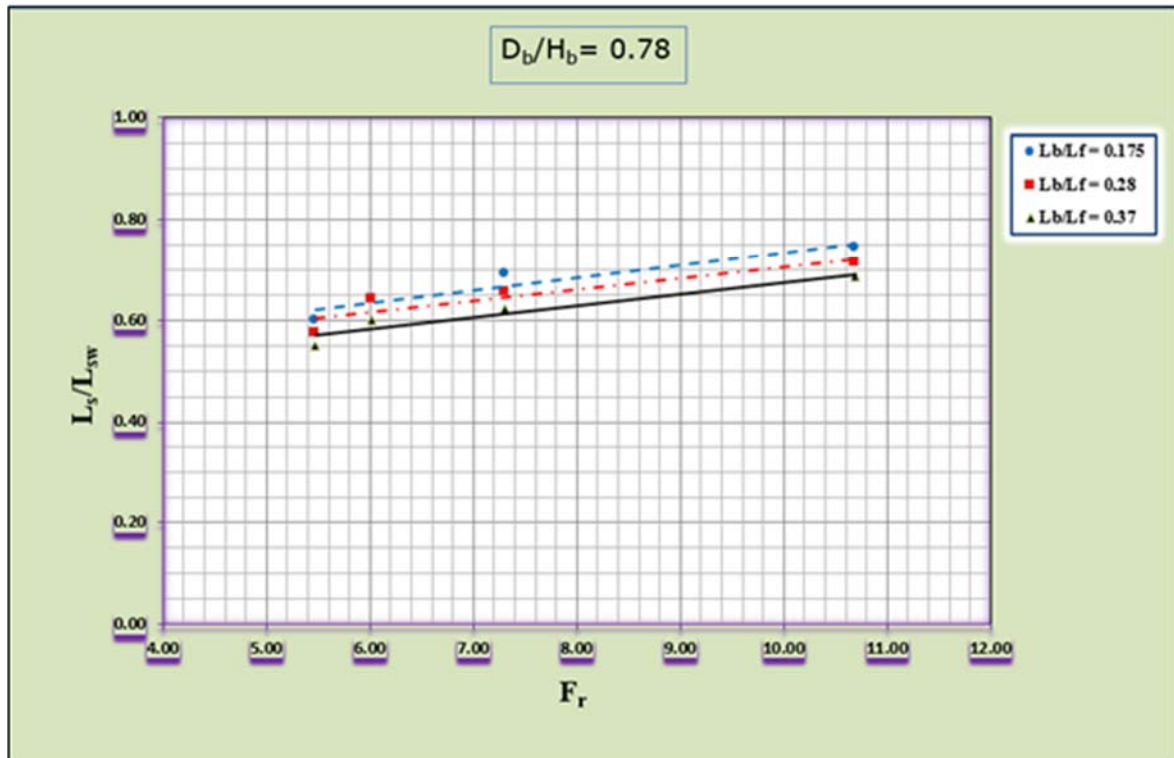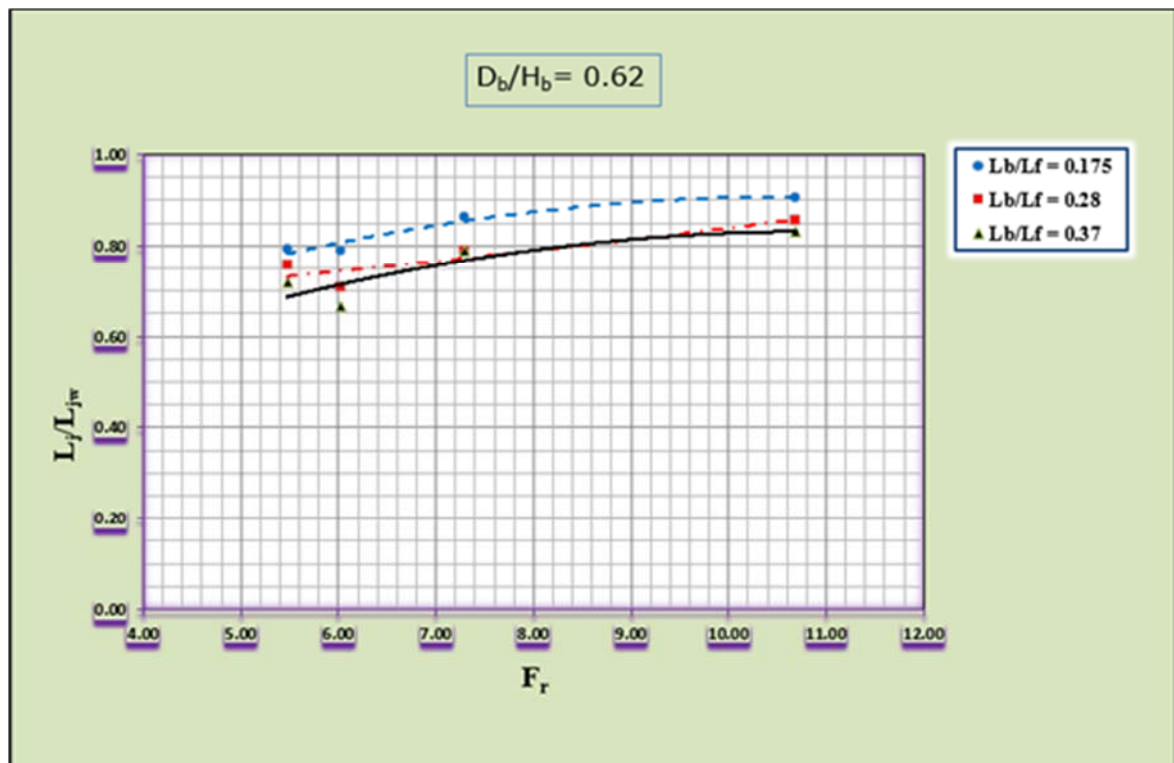Figure (8) Relation between (F_r) and L_s/L_{sw} for $D_b/H_b = 1.00$

Figure (9) Relation between (F_r) and Ls/Lsw for D_b/H_b = 0.78

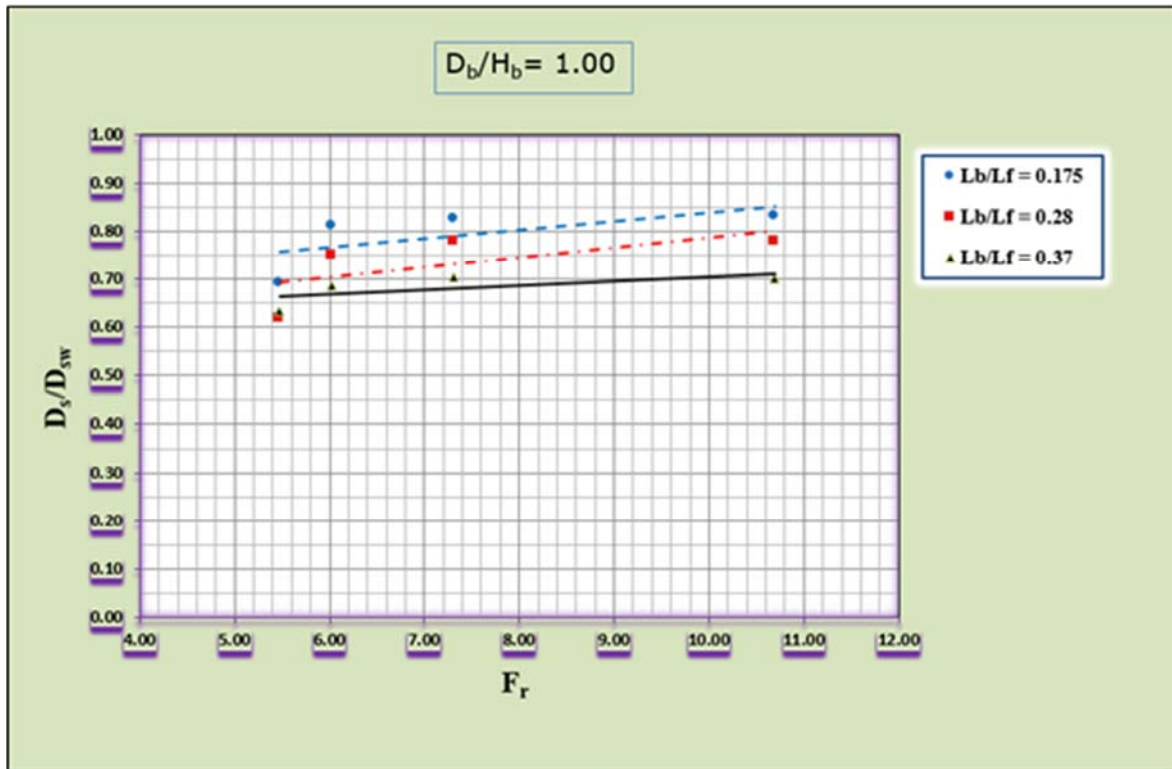Figure (10) Relation between (F_r) and L_s/L_{sw} for D_b/H_b = 0.62

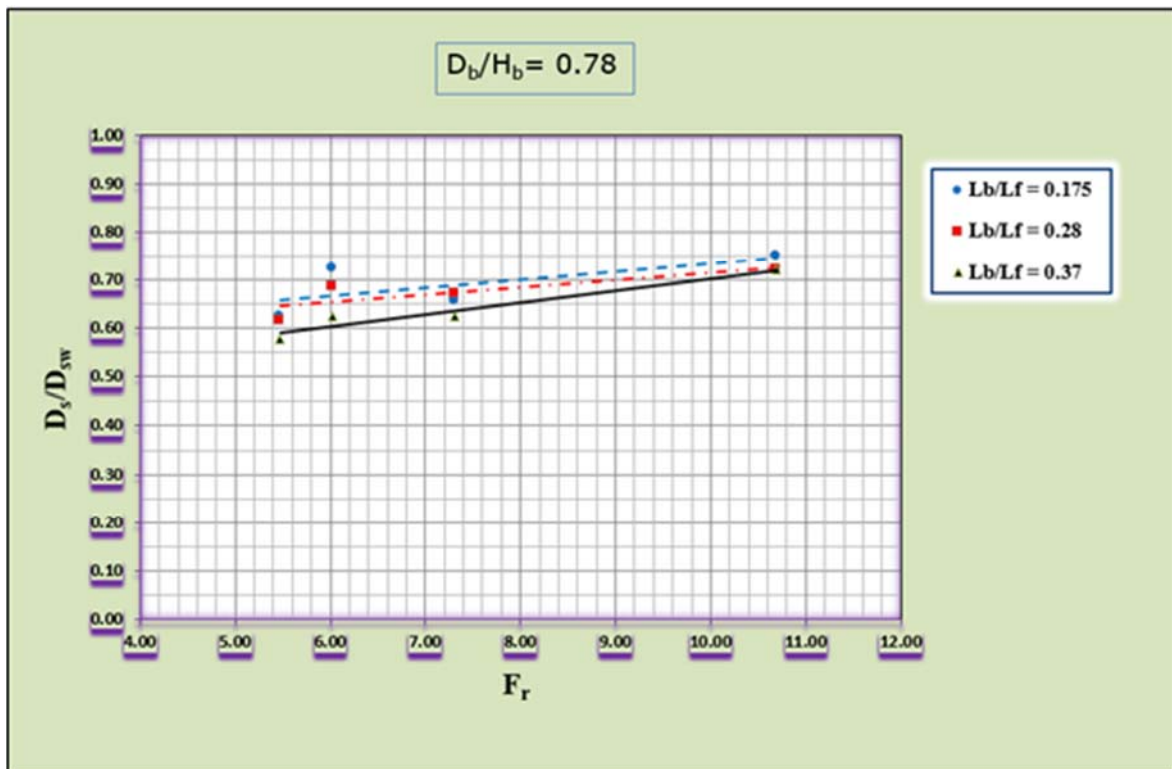Figure (11) Relation between (D_s/D_{sw}) and (F_r) for $D_b/H_b = 1.00$

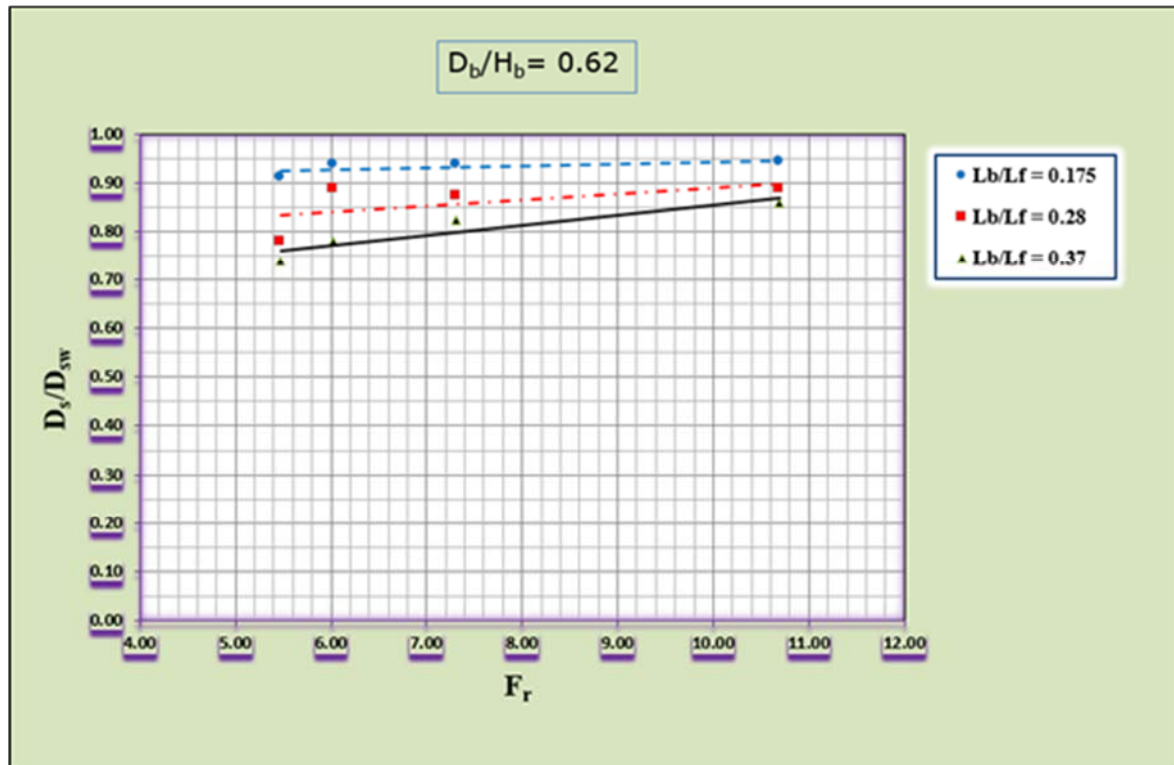Figure (12) Relation between (D_s/D_{sw}) and (F_r) for $D_b/H_b = 0.78$

Figure (13) Relation between (D_s/D_{sw}) and (F_r) for $D_b/H_b = 0.62$