A Modified Stilling Basin with Flow-Guide Pipes to Improve Hydraulic Jump Parameters

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Abstract - *the paper presents a novel technique to increase the efficiency of the stilling basin downstream the vertical gates. The paper proposed guide pipes of the flow to the side boundaries. The paper investigated the existence of one, two and three rows of two-column pipes on characteristics of the hydraulic jump. The results showed that the presence of three rows of flow-guide pipes with a length between their nozzles (L_{Open}/d_1 = 4.3) has definitely enhanced the characteristics of the hydraulic jump. The proposed basin reduced the length of the hydraulic jump by 31% and increased the energy Loss by 4% compared to the case of no flow-guide pipes.*

Key Words: (stilling basin, flow, guide pipes, hydraulic, and jump)

1. INTRODUCTION

The hydraulic jump was considered as an effective tool to control the flow downstream the hydraulic structures. Many papers investigated the hydraulic jump [2, 9, 10, 12, 13, and 15]. Babaali, et al. (2015) applied FLOW-3D model to simulate the jump characteristics formed in the stilling basin in the Nazloo Dam in Iran. Wang, & Chanson, (2015) found that there is a big mutual effect between the variations of the free surface and the roller turbulence.

Gavhane, et al. (2018) investigated the design of the jump in a stilling basin of the Gunjawani Dam. Deshmukh (2018) investigated the jump in a roughened bed with stones. It was indicated that, the height of the stones affected the energy loss. Mohamed (2010). Investigated the symmetric and asymmetric jumps in rectangle stilling basins.

Habib & Nassar (2013) investigated the jump in a roughened bed with curved elements. It was indicated that, the apron of ninety percent of staggered proposed curved elements increased the lost energy by 17%. Habib & Nassar (2014) proposed a modified lateral sill as a tool to dissipate the energy. It was indicated that, the application of the modified lateral moving sill positively improved the features of the hydraulic jump.

Nassar (2014) proposed a perforated vertical sluice gate as a tool to modify the features of the jump. An obvious improvement of the features of the jump was presented. Abdel-Aal, et al. (2016) investigated the use of two sluice gated worked together in the same vertical plane. It was presented as a tool to improve the characteristics of the jump. The proposed tool was an effective to decrease the length of the apron by 4.3%

The direct effect of the hydraulic jump is presented on the movable bed downstream the hydraulic structure. The scour depth and the length can be considered as a direct indicator to the efficiency of the jump. Many papers were presented to investigate the flow and scour characteristics downstream the hydraulic jump. Elfiky, et al. (2005) investigated the effect of multi-vents regulator on local scour. Abdel-Aal et al. (2004) investigated effect of operating regulators' vents on scour.

The recent paper presents a technique including guide pipes of the flow to the side walls to increase the efficiency of the stilling basin downstream the vertical gates. The paper investigated the existence of one, two and three rows of the pipes on the characteristics of the hydraulic jump. In addition, the length between nozzles of the flow-guide pipes was investigated.

2. THEORETICAL APPROACH

The technique of dimension analysis was applied to detect the main parameters affecting the free jump features downstream of the sluice gate at the presence of the proposed flow-guide pipes. The main equation describes the phenomenon was presented as shown in equation (1).

$$\frac{d_2}{d_1}, \frac{L_{JUMP}}{d_1} \& \frac{E_{LOST}}{E_1} = f(F_{r1}, \frac{A_{HOLE}}{{d_1}^2}, \frac{L_{Open}}{d_1}) \qquad (1)$$

Where: d_1 and d_2 are water depths at the beginning and end of the jump, respectively; L_{JUMP} is the jump length; E_{LOST} and E_1 are the lost energy through the jump and the total energy at the begging of the jump, respectively; F_{r1} is the Froude number at the begging of the jump; A_{HOLE} is the summation areas of flow guide pipes in one column; and L_{Open} is the length between nozzles of the flow-guide pipes.

3. EXPERIMENTAL WORK

The experiments were conducted in the laboratory of the fluid mechanics in the college of engineering, Umm Alqua university Branch in Alqonfudhah. The device on which the tests were conducted is an open channel of the following dimensions. The length is 110cm, the height is 15cm and the width is 7.7cm. The model is sketched as shown in figure (1). Figure (2) shows the hydraulic jump at the existence of the flow-guide pipes. A vertical sluice gate is located at the beginning of the flume. A movable gate is located at the downstream side of the flume to control the tail depth. The following discharge was measured using a digital flowmeter. The flowmeter existed in the inlet pipe. The depth and length of the flow were measured using fixed rulers that existed on the flume sidewall.

The flow measuring procedure consists of the following steps: 1- switch on the pump; 2- move the upstream sluice gate up to the desired opening height; 3- the downstream side movable gate is adjusted to generate the hydraulic jump at the specified location; and 4- the flow is left for 10 minutes to reach the Steady-state.

The measurements include the followings: 1- the water depth at the beginning of the jump (d_1); 2- the water depth at the end of the jump(d_2); 3- the jump length (L_{JUMP}); 4- the flow discharge (Q); and 5-the water depth upstream the sluice gate (H_{UP}). The different experimental models are presented as shown in figure (2A). The experimental works include two-stages. The first stage investigated the existence of one, two and three rows of the pipes on the characteristics of the hydraulic jump. The second stage investigated the length between nozzles of the flow-guide pipes. Table (1) shows the experimental model stages.

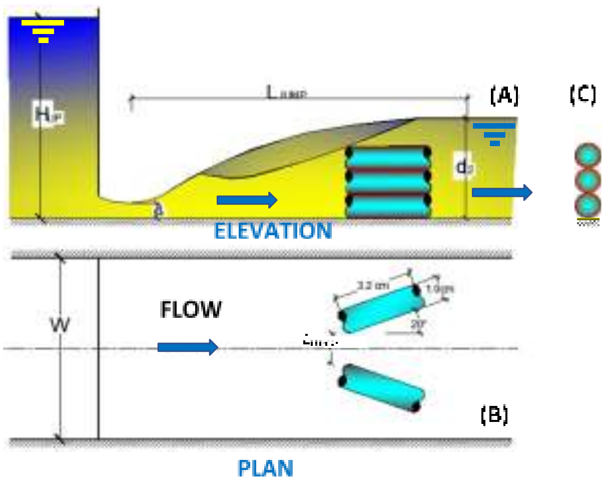


Fig -1: The sketches of experimental model [A] the elevation of the model including flow-guide pipes [B] the plan of the model [C] the side view of the flow-guide pipes

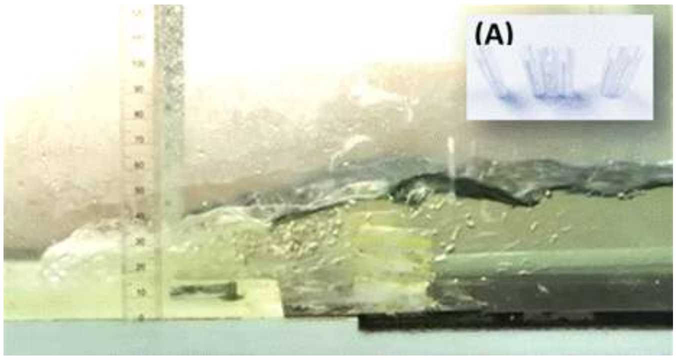
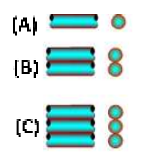
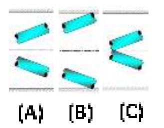


Fig -2: A photo of the experimental model [A] the used flow-guide pipes models

Table -1: The experimental model stages

Stage	The description	Tested parameters	Photos
I	In the first stage the effect of existence of one, two and three rows of the the flow-guide pipes was investigated	A. A_{HOLE}/d_1^2=1.34 (1-row) B. A_{HOLE}/d_1^2=2.68 (2-rows) C. A_{HOLE}/d_1^2=4.03 (3-rows)	
II	In the second stage , the length between nozzles of the flow-guide pipes was investigated.	A. L_{Open}/d_1=1.7 B. L_{Open}/d_1=4.3 C. L_{Open}/d_1=0.0	

4. RESULTS AND DISCUSSIONS

The relations between the different hydraulic jump features and F_{r1} were presented as a technique to investigate the experimental measurements. Chart (1) shows the relations between the ratio of water depths at the end and the beginning of the jump d_2/d_1versus F_{r1} for the different A_{HOLE}/d_1^2 (i.e., A_{HOLE}/d_1^2=4.03, 2.68 and 1.34).

It clears that, the accuracy of the fitting lines is very good the lowest value of R^2 =95%. Chart (2) shows the relations between the ratio of the jump length L_{JUMP}/d_1 versus F_{r1} for the different A_{HOLE}/d_1^2. Chart (3) shows the relations between the ratio of the lost energy E_{LOST}/E_1 versus F_{r1} for the different A_{HOLE}/d_1^2.

Chart (4A) shows the relations between d_2/d_1versus F_{r1} for A_{HOLE}/d_1^2=1.34, 2.68 and 4.03. It clears that, the case of A_{HOLE}/d_1^2= 4.03 gives minimum values of d_2/d_1 compared to other values of A_{HOLE}/d_1^2. Chart (4B) shows the relations between L_{JUMP}/d_1 versus F_{r1} for A_{HOLE}/d_1^2=1.34, 2.68 and 4.03.

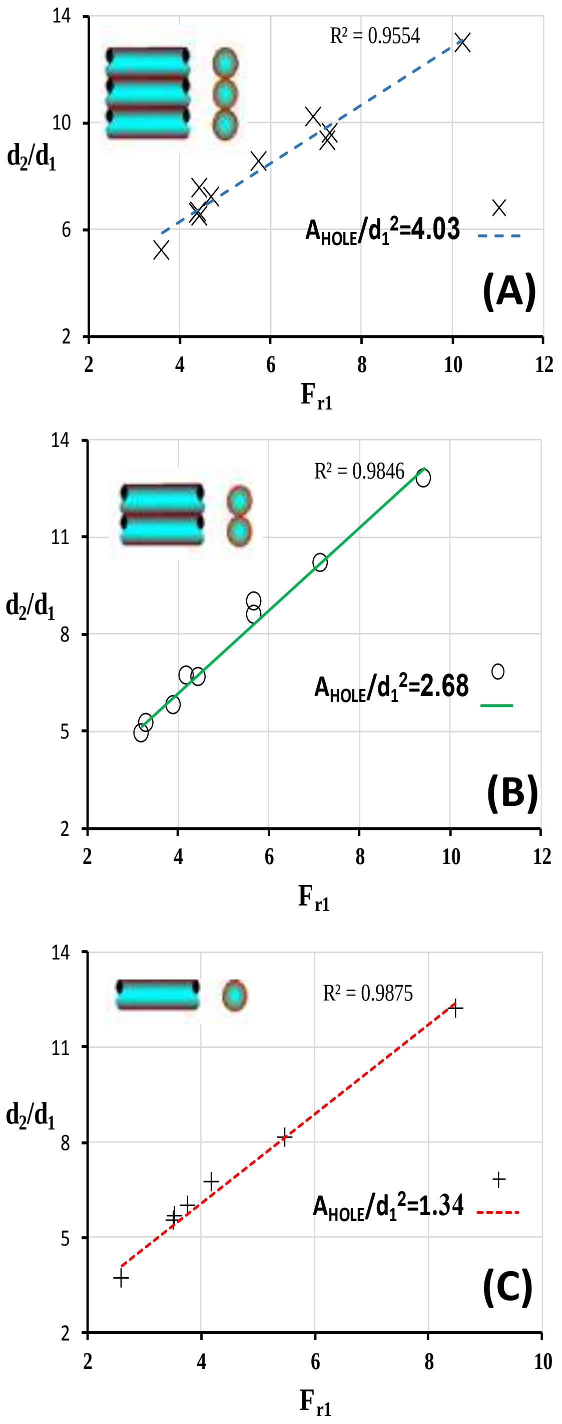


Chart -1: The relations between $\frac{d_2}{d_1}$ versus F_{r1} for the different $\frac{A_{HOLE}}{{d_1}^2}$

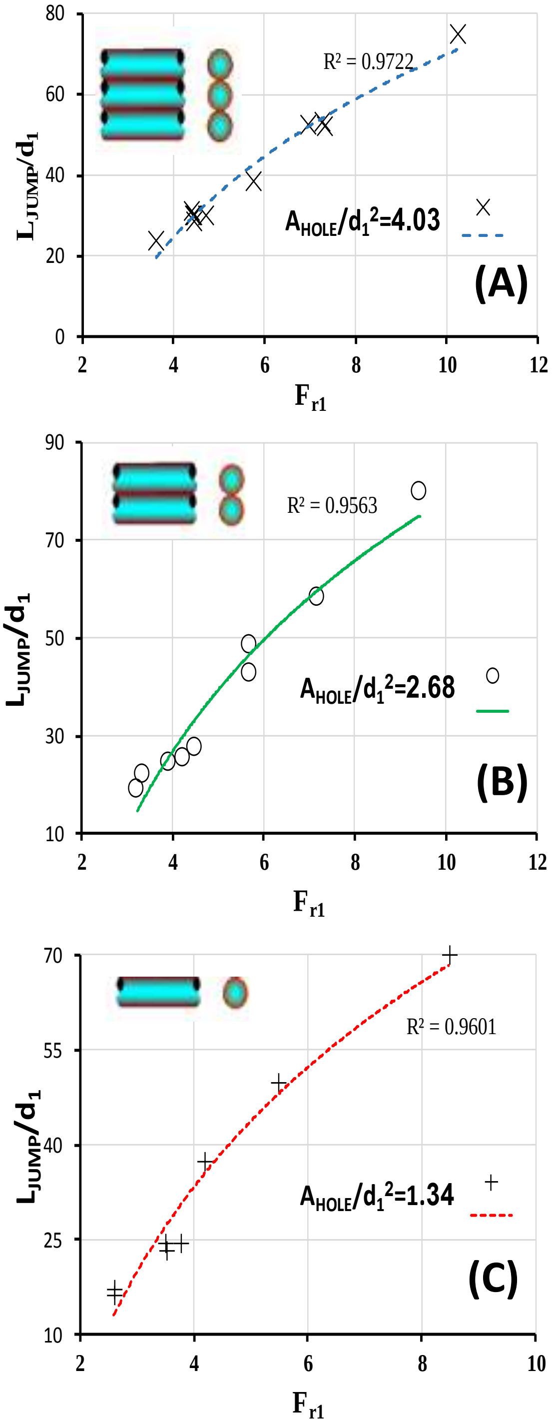


Chart -2: The relations between $\frac{L_{JUMP}}{d_1}$ versus F_{r1} for the different $\frac{A_{HOLE}}{{d_1}^2}$.

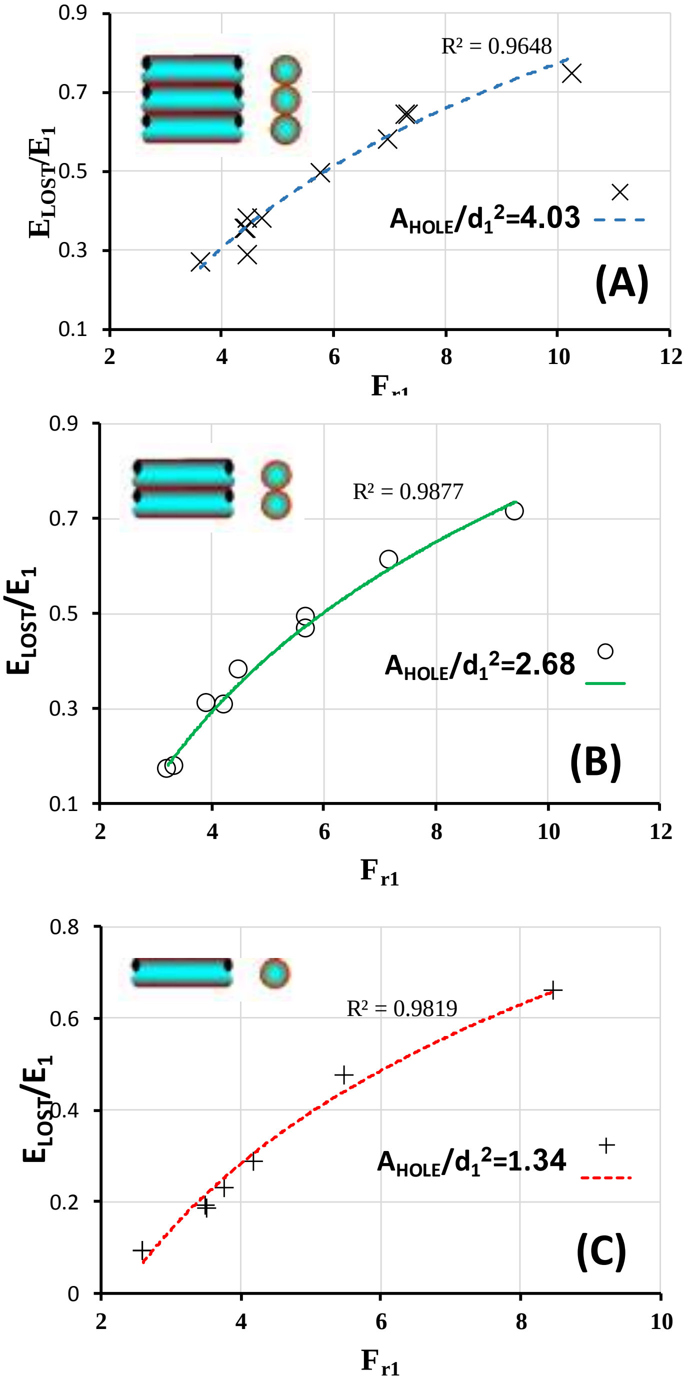


Chart -3: The relations between $\frac{E_{LOST}}{E_1}$ versus F_{r1} for the different $\frac{A_{HOLE}}{{d_1}^2}$

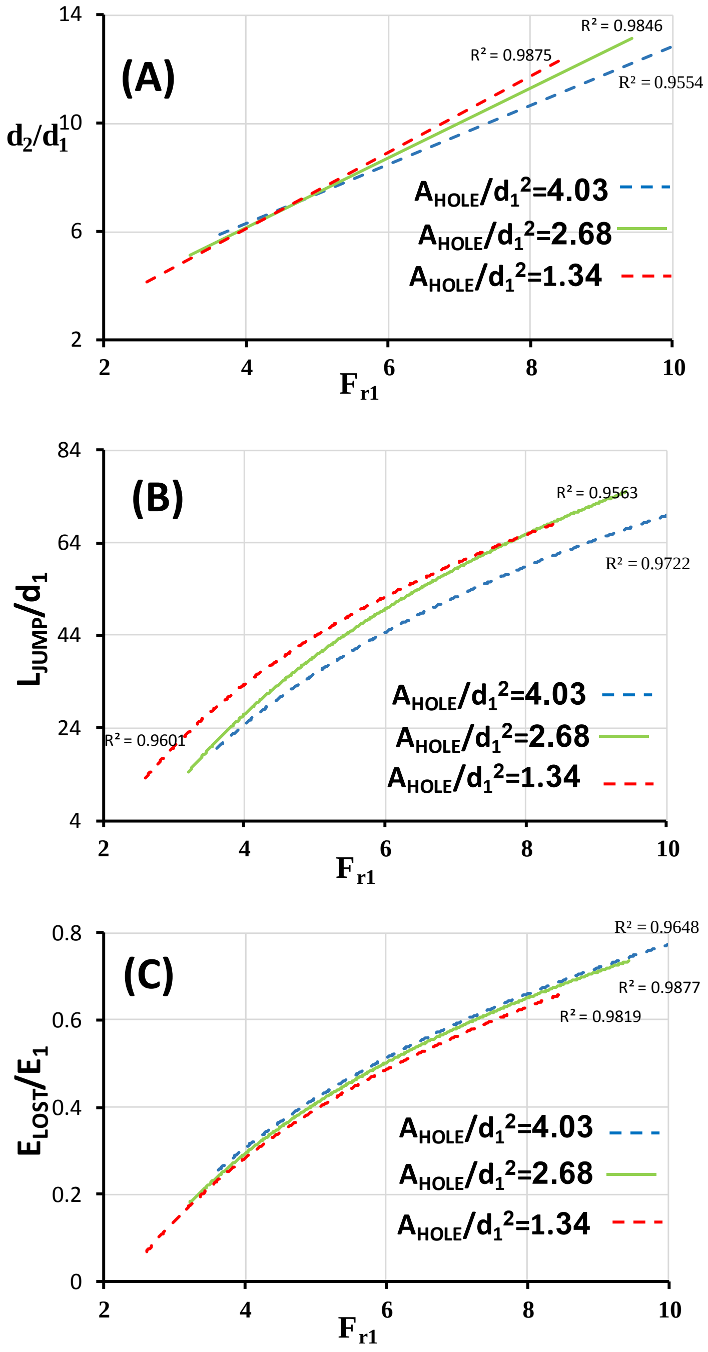


Chart -4: The relations between the different jump characteristics versus F_{r1} for the different $\frac{A_{HOLE}}{{d_1}^2}$.

It clears that, the case of A$_{HOLE}$/d$_1^2$= 4.03 gives the minimum values of L_{JUMP} /d$_1$ compared to other values of A$_{HOLE}$ /d$_1^2$. Chart (4C) shows the relations between E_{LOST}/E_1 versus F_{r1} for A$_{HOLE}$ /d$_1^2$=1.34, 2.68 and 4.03. It clears that, the case of A$_{HOLE}$ /d$_1^2$= 4.03 gives the highest values of E_{LOST}/E_1 compared to other values of A$_{HOLE}$ /d$_1^2$.

Chart (5) shows the relations between the ratio of water depths at the end and beginning of the jump d_2/d_1 versus F_{r1} for the different L_{Open} /d$_1$(i.e., L_{Open} /d$_1$=1.7, 4.3 and 0.0).

It clears that, the accuracy of the fitting lines is very good and the lowest value of R^2 =95.5%. Chart (6) shows the relations between the ratio of the jump length L_{JUMP} /d$_1$ versus F_{r1} for the different L_{Open} /d$_1$. Chart (7) shows the relations between the ratio of the lost energy E_{LOST}/E_1 versus F_{r1} for the different L_{Open}/d$_1$.

Chart (8A) shows the relations between d_2/d_1 versus F_{r1} for L_{Open}/d$_1$.=0.0, 1.7 and 4.3. It is clear that, the case of L_{Open}/d$_1$ =4.3 gives the lowest values of d_2/d_1 compared to other values of L_{Open}/d$_1$. Chart (8B) shows the relations between L_{JUMP} /d$_1$ versus F_{r1} for L_{Open} /d$_1$=0.0, 1.7 and 4.3.

It clears that, the case of L_{Open}/d$_1$= 4.3 gives the lowest values of L_{JUMP} /d$_1$ compared to other values. Chart (8C) shows the relations between E_{LOST}/E_1 versus F_{r1} for L_{Open} /d$_1$=0.0, 1.7 and 4.3. It is clear that, the case of L_{Open}/d$_1$= 4.3 gives the highest values of E_{LOST}/E_1 .

Chart (9A) shows the relations between d_2/d_1 versus F_{r1} for the case of no pipe guides and the new proposed basin (A$_{HOLE}$ /d$_1^2$= 4.03 and L_{Open}/d$_1$.= 4.3). It clears that, the case of the new basin gives the lowest values of d_2/d_1 compared to the case of no pipe guides. It reduced the relative depth of the investigated jump d_2/d_1 by 14.7%. Chart (9B) shows the relations between L_{JUMP} /d$_1$ versus F_{r1} for the case of no pipe guides and the new basin. It is clear that, the case of the new basin reduced the relative length of the hydraulic jump by 31%. Chart (9C) shows the relations between E_{LOST}/E_1 versus F_{r1} for the case of no pipe guides and the new basin. The new basin increased the energy Loss by 4% compared to the case of no flow-guide pipes.

5. CONCLUSIONS

The recent paper proposed guide pipes of the flow to the side boundaries. The paper investigated the existence of one, two and three rows of the pipes on characteristics of the hydraulic jump. The results showed the following conclusions:

- The case of three rows of flow-guide pipes, (A$_{HOLE}$ /d$_1^2$= 4.03) gives the lowest values of d_2/d_1 and L_{JUMP} /d$_1$. In contrast, it gives the highest values of E_{LOST}/E_1.
- The case of two columns of three rows of flow-guide pipes with length between their nozzles (L$_{Open}$/d$_1$ = 4.3) gives the lowest values of d_2/d_1 and L_{JUMP} /d$_1$. In contrast, it gives the highest values of E_{LOST}/E_1 .
- The new basin reduced the relative depth of the jump d_2/d_1 by 14.7%;
- The new basin reduced the relative length of the hydraulic jump by 31%.
- The case of the new basin increased the energy Loss by 4%.

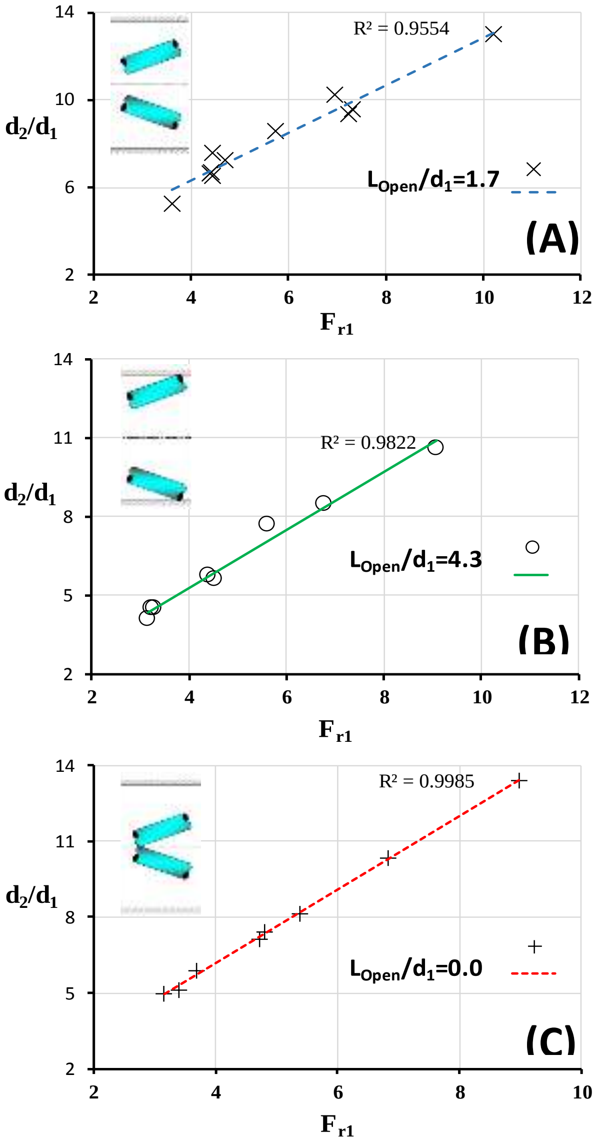


Chart -5: The relations between $\frac{d_2}{d_1}$ versus F_{r1} for the different $\frac{L_{Open}}{}$

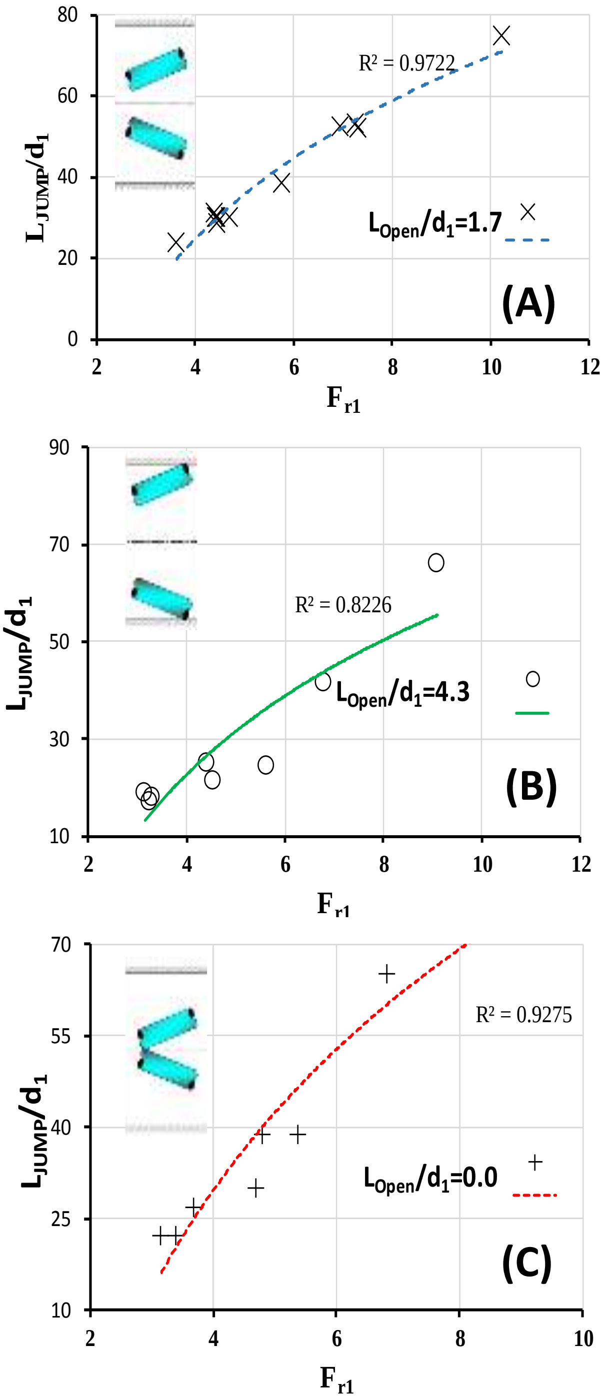


Chart -6: The relations between $\frac{L_{JUMP}}{d_1}$ versus F_{r1} for the different $\frac{L_{Open}}{d_1}$.

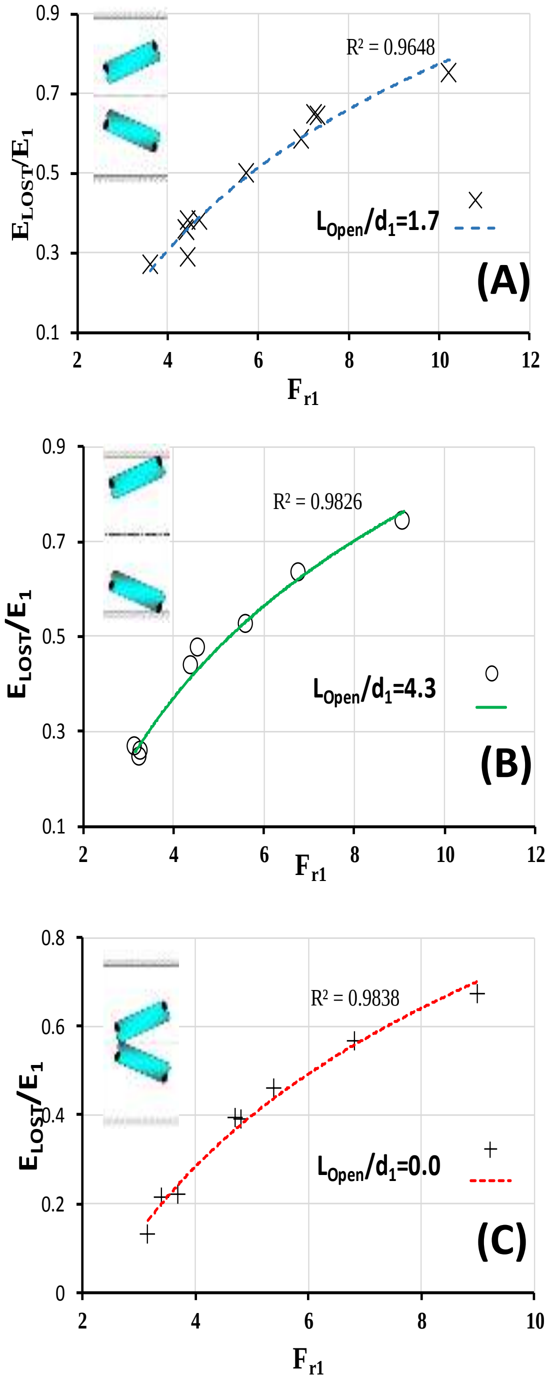


Chart -7: The relations between $\frac{E_{LOST}}{E_1}$ versus F_{r1} for the different $\frac{L_{Open}}{d_1}$

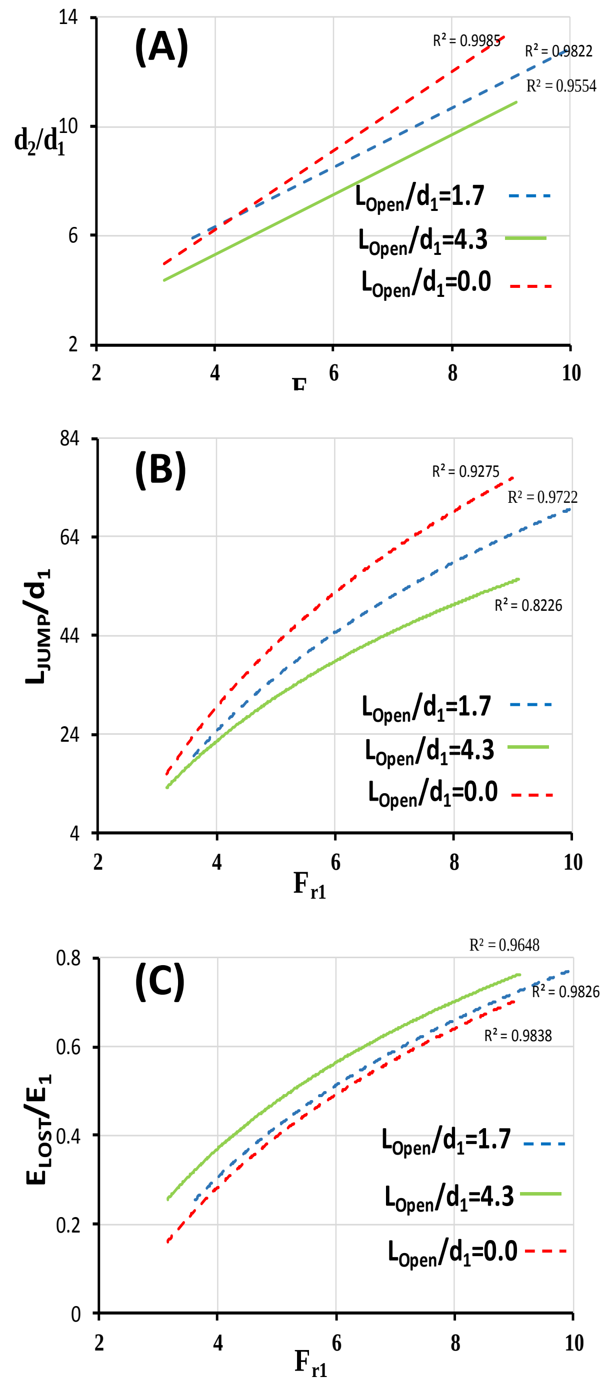


Chart -8: The relations between the different jump characteristics versus F_{r1} for the different $\frac{L_{Open}}{d_1}$.

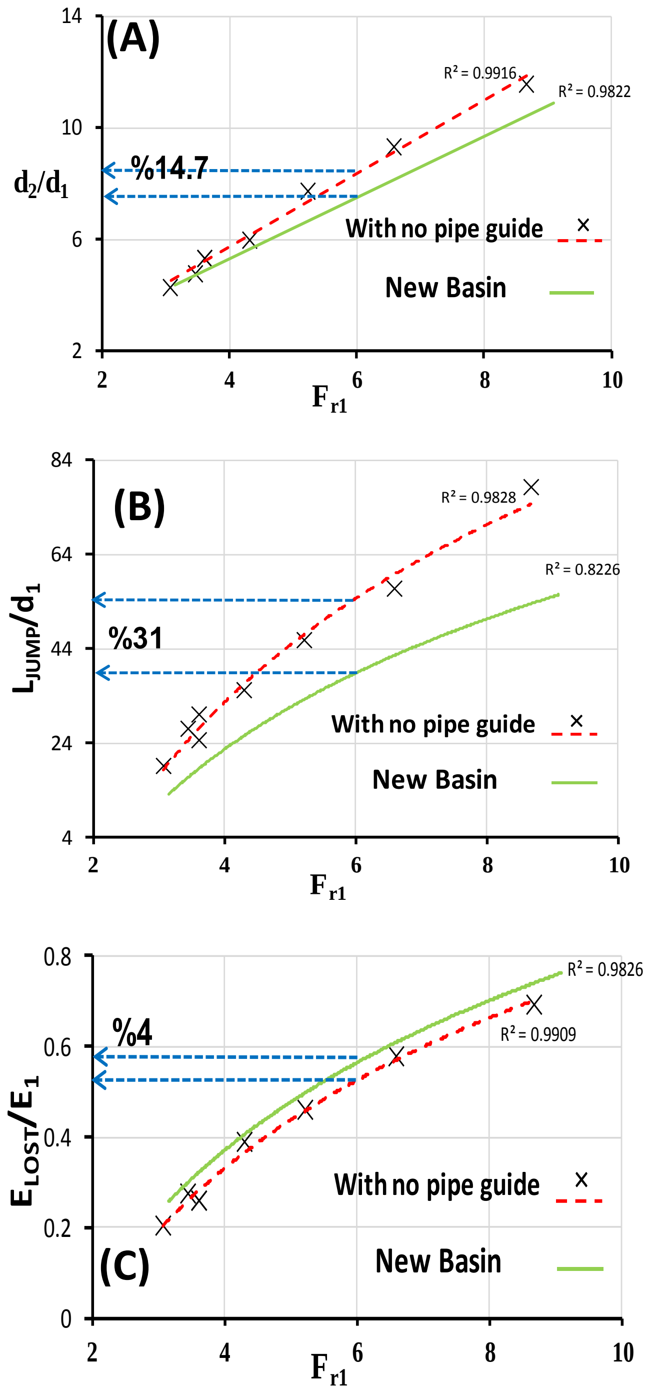


Chart -9: The relations between the different jump characteristics versus F_{r1} for the new basin and the case of no pipe guide.

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