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Numeric Study of Flow Pattern in Upstream and Downstream of Side Intakes Using Flow3d Software (Case Study Gotvand Regulatory- Deviant Dam Aqili intake)

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ABSTRACT
Having knowledge of flow structure or pattern is very essential in many hydraulic phenomena, particularly intake structures, since the flow discharge rate and also sediment entering the intake are vastly dependent on the characteristics of this pattern. In this research, simulation was done using Flow 3D software in order to investigate flow pattern in upstream and downstream of Aqili intake and in 4 states of disruption and maximum discharge. The achieved results of software output indicated that in Aqili intake at 4 states of valve disruption, when valve disruption height increases, due to water velocity decrease, hydraulic jump length also decreases. Moreover, as Froude number increases, hydraulic jump length also increases and this is because with increase in Froude number, flow velocity increases as well. All the output parameters of the software are indicative of the direct effect of velocity in horizontal line on jump length and this demonstrates the validity of analyses. In addition, the achieved results point to a more appropriate design than the designed discharge for Aqili intake.
Key Words: *Froude Number, Hydraulic Jump, Gotvand Regulatory Dam, Aqili intake, Flow 3D*

INTRODUCTION

Because of their special impact on human life and shaping diverse civilizations, rivers have always beckoned humans to use the gift of water. Rivers provide water and energy for nature and human beings and we can say that water supply is the most important economic role of rivers. Water deviation from its major path is utilized for various purposes including agriculture, Urban Water Supply, electricity generation, etc. using intakes.

Due to the significance of rivers as one of the essential resources of water supply, dewatering and flow branching from rivers are one of the discussions which we always face in hydraulic and river engineering. Flow in a dewatering branching is innately a three dimensional flow and complicated.

Dewatering from rivers by gravity method is one of the most common methods of dewatering. Despite designing and conducting various intakes due to the three dimensional nature of flow, it is inevitable to use mathematical models against intakes, especially for the intakes with high capacities.

Knowing the flow structure or pattern is very essential in many hydraulic phenomena, especially intake structures, since flow discharge rate and also sediment entering the intake, to a great extent, depends on the characteristics of this pattern.

Predicting flow pattern conditions will assist engineers to design intakes with most discharge and least deviatory sediment and or consider the appropriate methods of controlling sediment entering intakes in similar water load conditions. The performed studies regarding three dimensional flow patterns in side intakes have been few and by the progress of mathematical models and development of measuring tools, these studies need to be conducted with more accuracy. Examining flow characteristics and reciprocal behavior of flow and sediment is a complicated phenomenon and sometimes exceedingly costly.

Procuring a physical model, using expert experiences, applying mathematical models in flow simulation in one, two and three dimensional modes are some of the methods which can be utilized in the investigation of flow pattern. Considering the three dimensional nature of flows in the real world, applying three dimensional mathematical models in river engineering can be the key to technical challenges.

RESEARCH THEORY AND BACKGROUND

Christodoulou [1] performed some tests in order to reach a criterion of forming hydraulic jump conditions in combining three-branch rectangular flows. His analysis has been explained based on one dimensional momentum equation. He offered the results of his work in a figure which was divided into ranges of hydraulic jump and lack of creating hydraulic jump. Shubayek et al. [2] offered a dynamic model to analyze subcritical flows at channel junctions. This model has the ability to calculate and estimate upstream depth, using motion momentum equation and mass survival law in two control volumes with a common border and having information such as downstream discharge and downstream depth. The parameters utilized in this model were shear forces between two control volumes and shear border friction force of flow separation zone. The investigation and comparison of laboratory data and prediction of the offered model demonstrated that prediction model and observations based on tests matched with each other. Webber and Greated [3] mentioned the analysis of flow at channel junctions and concentrated their investigations on junction's upstream and downstream depths. They considered different angles of channel junction angle (δ) in their studies and surveyed the channel's sidewall curve. Hager [4] examined the three-branch flow whilst the three-branch upstream and the subsidiary branch has been transformed into subcritical flow and at downstream had been turned into supercritical flow.

Ead and Rajaratnam [5] did laboratory studies about hydraulic jumps on corrugated beds. The tests were performed for Froude number 4 to 10 and the relative roughness t/Y1, in which t is the corrugation height and Y1 is water depth before jump, were selected between 0.25 and 0.5 and studied. They reached the conclusion that tailwater depth required to create hydraulic jump on corrugated beds is smaller than classic hydraulic jump (flat bed) and jump length is also approximately half the jump length in flat beds.

Lien et al. [6] investigated the flow pattern in 90 degree and 180 degree arcs, using two-dimensional depth-averaged mode. For the 90 degree arc, measuring results indicate that the main component of velocity rate increases around outer walls at channel length and due to the lateral longitudinal momentum transfer property by secondary flow, velocity rate in outer wall length is more than inner wall.

Yazdi et al. [7] examined the numeric flow pattern in hydraulic jump stilling basin, using VOF. They explored hydraulic jump phenomenon, which is one of the significant flow energy dissipaters in hydraulic engineering, using FLOW3D software and demonstrated that the software can predict velocity-depth distribution in hydraulic jumps. Moreover, they revealed that, in this test, RNG turbulence model provides more appropriate results than$k-\varepsilon$. Kamanbedast and Farajpour [8] simulated bottom intake flow, using the Flow 3D software. Their results indicated that the best slope for dewatering is 20 degrees. On the other hand, the more intake disruption increases, the more the deviant discharge rate will be. Furthermore, changes in coefficient of flow intensity in diverse modes compared to Froude number and intake network disruption rate will cause decrease in coefficient of flow discharge.

MATERIALS AND METHODS

Geographical Condition of Gotvand Regulatory- Deviant Dam

Gotvand regulatory dam is situated in the north east of Gotvand city and 3 kilometers away from the city on Karoon River. This dam, which is an earth dam with concrete valve overflow, has been built in the south west of Iran in Khoozestan Provence and western edge of the central Zagros Mountains and with the coordinate 40-48 east and 10-32 north.

Aqili Intake

Aqili intake, located in the eastern edge of Gotvand Regulatory- Deviant Dam, includes: a valve of the sector type with dimensions 2*2.5, intake capacity or designed discharge 12m^3/s. Upstream channel level (from the bottom): 200 meters above sea level, upstream channel level (from the top): 206 meters above sea level, downstream channel level (from the bottom): 199 meters above sea level, downstream channel level (from the top): 201.7 meters above sea level.

Introducing the Software and Problem Solving method:

Flow3D is dynamic computational fluid software, which has a lot of applications for modeling complex three-dimensional, steady and unsteady conditions with irregular shape and geometry. Alternative applications of this software are hydraulic simulations of sediment problems and also problems regarding transfer and distribution phenomena in the environment. Benefits of using Flow3D software are being more user-friendly than similar softwares and, quick implementing and designing borders and solid geometry and also networking, providing guide texts in order to better simulate, automatic selection of the best timescales and without needing to define the initial timescale and other advantages. This software has the potential to display instantaneous changes of various hydraulic parameters such as depth and velocity in different directions and in each desired section of the structure as a graphic or text file [9].

This software utilizes various methods to analyze models. In this study, RNG model has been used, which has an acceptable and high accuracy. It should be mentioned that in this research, Flow3D software Ver. 10.0.1 has been applied. The output of hydraulic jump features of Flow3D software was compared with physical relationships regarding hydraulic jump, as demonstrated below:

1) $L_j = 3y_2 Fr_1^{1/2}$ → $2/5 < Fr_1 < 1$

2) $L_j = 5(y_2 - y_1)$ → $4.5 < Fr_1 < 2/5$

3) $L_j = 6y_2$ → $9 < Fr_1 < 4.5$

In above relationships, Fr_1 is Froude number before hydraulic jump occurrence, L_j is hydraulic jump length (m) and y_2, y_1 are depth before and after hydraulic jump (m), respectively [10].
To this end, first Aqili intake shape was mapped as three-dimensional using AutoCAD software and then FLOW3D software was recalled. Afterwards, by entering hydraulic data relevant to Aqili intake in Flow3D software, we began flow simulation. After becoming sure of the correctness and accuracy of mathematical model for further investigation and reaching the best mode of intake valve disruption, we attempted to generate minimum flow turbulence and maximum discharge. In this study, in order to examine upstream and downstream flow pattern, maximum discharge $8m^3/s$ at 4 modes of valve disruption (0.6, 0.9, 1.25, 1.7m) was considered.

RESULTS AND DISCUSSION
After offering the above mentioned explanations, in this part, we examine the results. This research consisted of 4 scenarios and to analyze these scenarios, the software worked 10 times altogether, 6 of them unacceptable. In order to calibrate the results, first 0.6m height of intake valve disruption at discharge $8m^3/s$ was compared, using manning equation. To enhance the accuracy of output results, it was decided that mesh happen as a separate part; all in all, Aqili intake consisted of 253368 cells, figure (1).

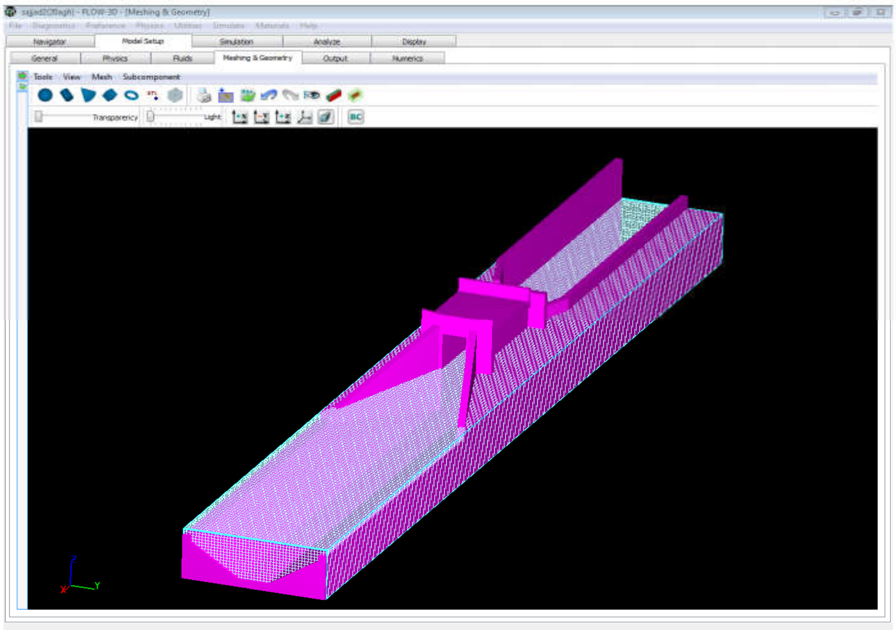

Figure (1) A view of a mesh made

Calibration and Validation of Mathematical Model

Health control of a phenomenon or an event with confirmed standard phenomenon is called calibration. In this study, the concept of calibration, i.e. matching results of mathematical model to reality; here, results of manning equation has been used:

$$V = \frac{1}{n} S^{\frac{1}{2}} R^{\frac{2}{3}} \qquad (4)$$

For this purpose, on a point at a distance of 34m from Aqili intake center and at level 199m, for each discharge $8m^3/s$, flow speed was 2.1m/s, which matched more with the speed of 1.9m/s achieved from manning equation (table 1).

Table (1) Results of Calibration Model

Title	Discharge (CMS)	Measuring speed from manning equation (m/s)	Measuring speed in mathematical model (m/s)	Error rate
Aqili Intake	8	1.9	2.1	10.52

Analyzing Results

After calibration of the software and ensuring the accuracy of results and outputs, the data were examined. After implementing the software and starting mathematical model for Aqili intake with different disruption heights and for each maximum discharge $8m^3/s$, the achieved results were provided. Figures 2 to 5 display the results of passing flow below Aqili intake valve simulation, using the software. Furthermore, in disruption heights of 1.7m, hydraulic jump does not occur (figure 5) and this indicates that the discharge designed for the intake is appropriate. Comparing hydraulic jump length in the intake with disruptions 1.25m, 0.9m, 0.6m (figure 6), it is concluded that increasing the height of intake valve disruption, due to speed decrease, would reduce hydraulic jump.

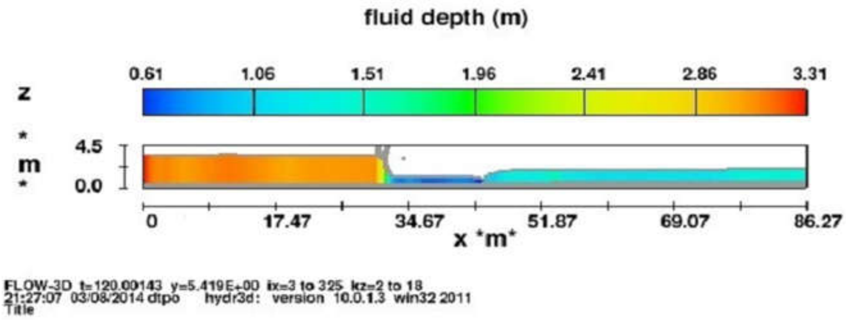

Figure (2) fluid depth in 0.6m Aqili intake disruption

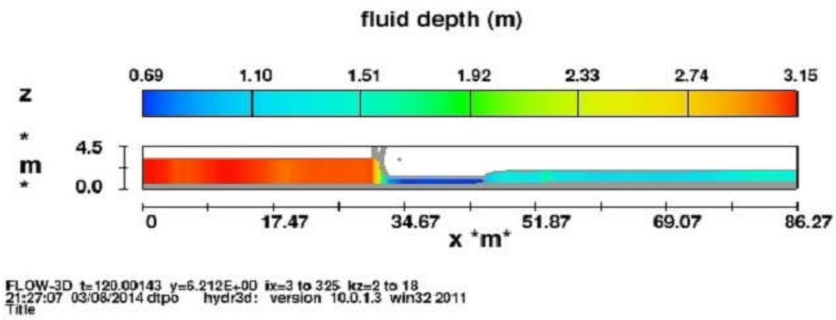

Figure (3) fluid depth in 0.9m Aqili intake valve disruption

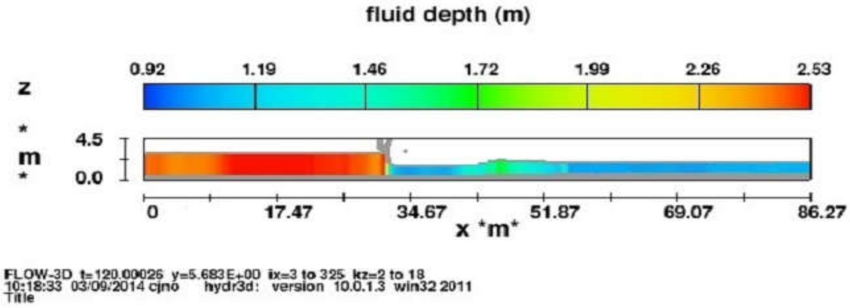

Figure (4) fluid depth in 1.25m Aqili intake valve disruption

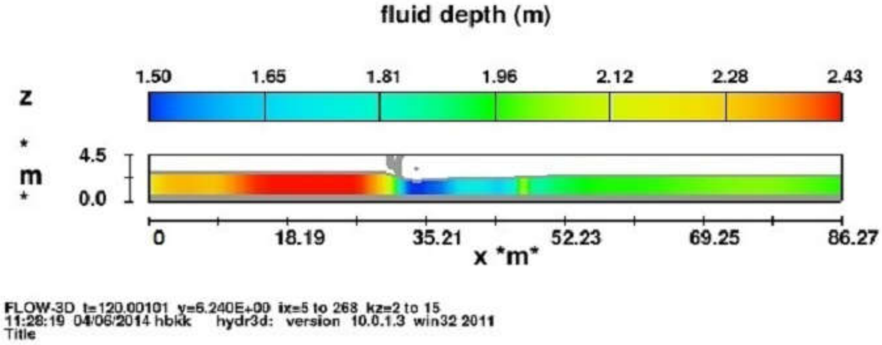

Figure (5) fluid depth in 1.7m Aqili intake valve disruption

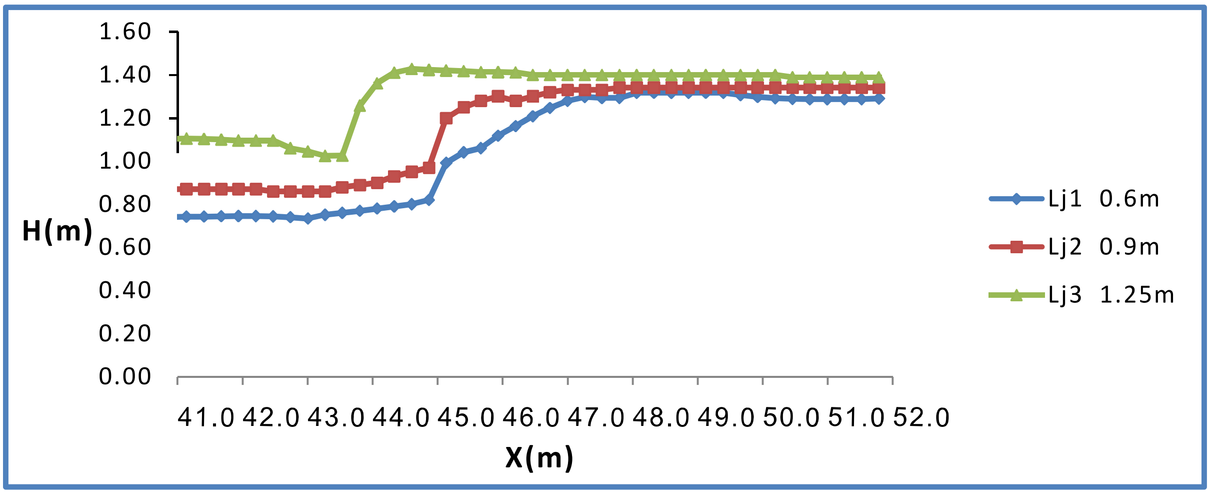

Figure (6) jump length comparison in Aqili intake (H fluid height, X length)

Table (2) jump length characteristics in Aqili intake

Title	Valve disruption height (m)	Fluid depth before jump y1 (m)	Fluid depth after jump y2 (m)	Froude number Fr_1	Maximum speed (m/s)	Jump length in model (m)	Jump length in equation (m)
Aqili Intake	0.6	0.74	1.29	2.4	6.45	10.92	11.06
	0.9	0.86	1.34	2.2	5.7	8.9	10.35
	1.25	1.1	1.4	1.6	4.88	6.72	7.38
	1.7		Without jump				

Investigating effect of Froude number and average velocity on hydraulic jump length

In order to examine the effect of flow average velocity and Froude number on hydraulic jump length, output results of software have been demonstrated for Froude number and velocity in four different disruption modes (0.6, 0.9, 1.25, 1.7m) in discharge 8m³/s (figures 7 and 8).

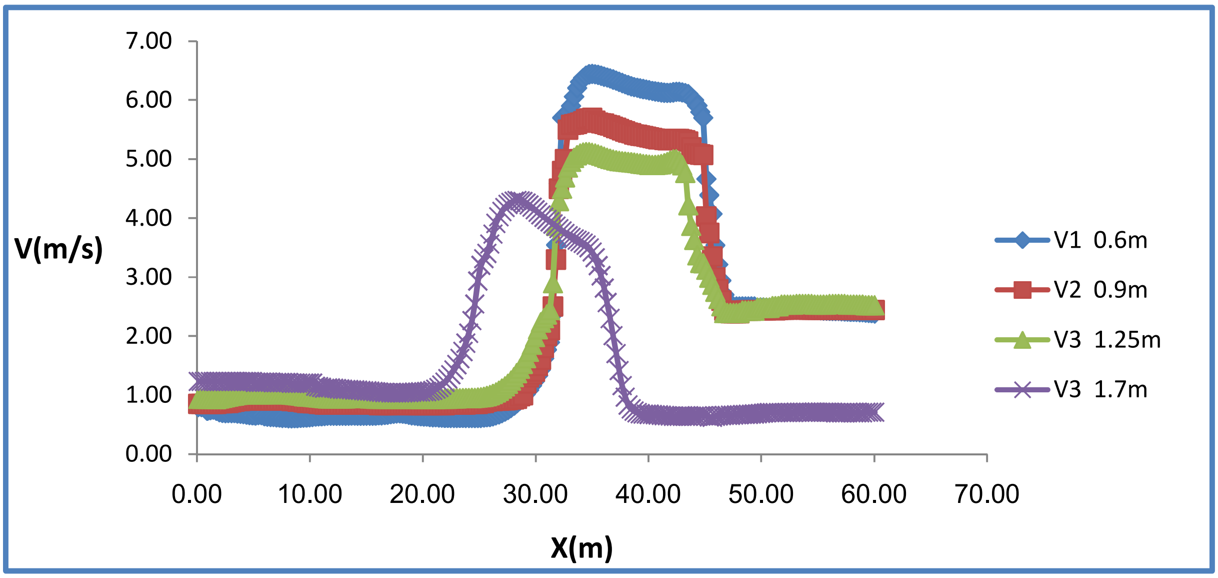

Figure (7) average velocity in Aqili intake four disruption modes (V average velocity, X length)

Results achieved by comparing average velocity in four disruption modes in the intake reveal that increasing valve disruption height would reduce velocity (figure 7).

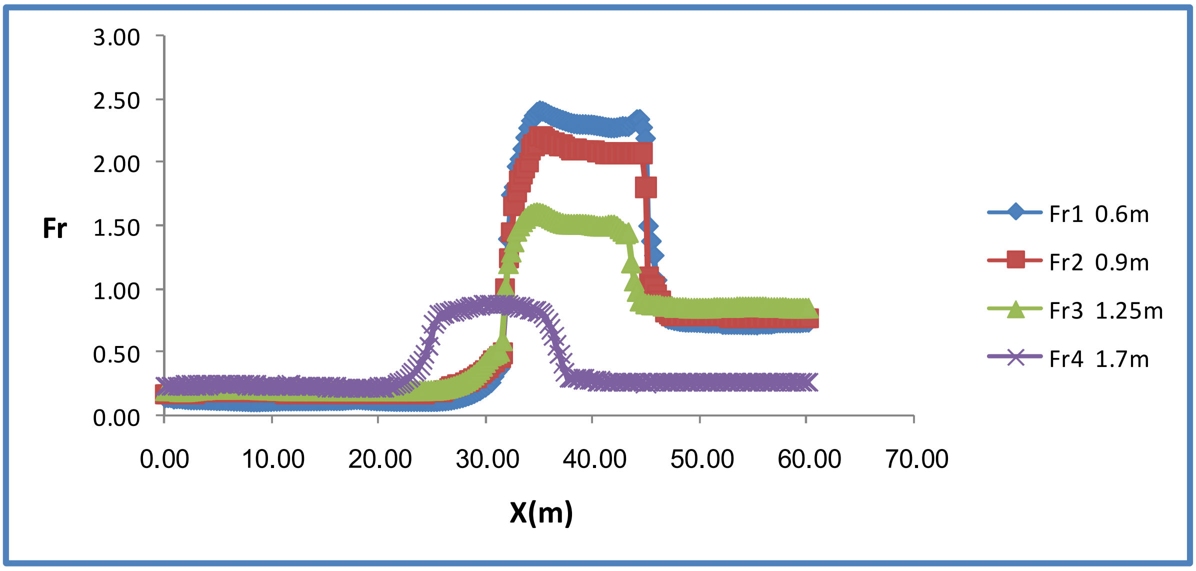

Figure (8) comparing Froude number in Aqili intake four disruption modes (Fr Froude number, X length)

As demonstrated in figure (8), increasing valve disruption would reduce Froude number and this is due to the fact that with Froude number increasing, flow velocity also increases and in all disruptions with Froude number becoming larger, jump length will increase as well. Because Froude number has a direct relationship with average velocity, and, on the other hand, flow velocity has a direct linear relationship with discharge, thus increase in each of these parameters would cause increase in the other two parameters and decrease in each of them would lead to decrease in the other two. Results indicate that there is a accurate and meaningful relationship between mathematical equations and output data of the software. All the output parameters of the software are indicative of the direct horizontal effect of velocity on jump length and this proves the ACCURACY of the analyses.

CONCLUSION

The results of studies undertaken can be provided as follows:

1. The results indicated that in Aqili intake the best valve disruption mode is at 1.7m height, since at this disruption height no hydraulic jump or energy loss would occur and this reveals that the designed discharge capacity is suitable for the intake.
2. Results indicated that the highest Froude number in Aqili intake equals ($F_{rmax} = 2.4$) at valve disruption height of 0.6m.
3. Results indicated that the least jump length in Aqili intake occurs at disruption height of 1.25m with the Jump length ($L_{jmin} = 6.72m$).
4. Results indicated that the highest jump length in Aqili intake occurs at the disruption height of 0.6m with jump length ($L_{jmax} = 10.92m$).
5. All output parameters of the software are indicative of the direct effect of velocity on hydraulic jump length and this proves accuracy of the analyses.
6. Results of examining the effect of Froude number on jump length demonstrated that with Froude number increase in each Aqili intake valve disruption, the jump would increase and the reason is that, like Froude number, the flow speed increases as well.

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