Advances in Environmental Biology, 8(21) October 2014, Pages: 1202-1208

AENSI Journals

Advances in Environmental Biology

ISSN-1995-0756 EISSN-1998-1066

Journal home page: http://www.aensiweb.com/AEB/

Numerical Study of Flow Patterns in Lateral Intakes Upstream and Downstream (Case Study: Gotvand Diversion Dam)

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ARTICLE INFO

Article history:
Received 25 October 2014
Received in revised form
26 November 2014
Accepted 29 December 2014
Available online 15 January 2015

Keywords:
Froude number, intake, hydraulic jump, Flow 3d.

ABSTRACT

Knowledge of the structure or flow pattern in many hydraulic phenomena especially intake structures is essential, because the rate of flow discharge as well as sediment input into the intake largely depends on the characteristics of this pattern. In this study, to investigate the flow pattern in upstream and downstream of the Gotvand intake in four modes of opening and in the maximum discharge was simulated using 3-dimensional software Flow 3d. The results of the software output showed that in four modes of Gotvand intake, by increasing the height of gates' opening in the intake, the hydraulic jump decreases due to water velocity reduction. Also hydraulic jump length increases by increasing Froude number and this is due to the fact that the flow rate increases with increasing Froude number. All the software output parameters show the direct impact of speed in the horizontal line on jump length and this indicates the accuracy of the analysis. The results also confirm the appropriate design to the discharge designed for both Aghili and Gatvand intakes.

To Cite This Article: Sajad Nouri and Ebrahim Nohani, Numerical Study of Flow Patterns in Lateral Intakes Upstream and Downstream (Case Study: Gotvand Diversion Dam). ***Adv. Environ. Biol., 8(21),*** *1202-1208, 2014*

INTRODUCTION

Impoundment from rivers using gravity method is of the most common methods of impounding. Despite the numerous intakes design and implementation, using mathematical models, especially for high-capacity intakes is inevitable due to the three-dimensional nature of the flow against intakes. Knowledge of the structure or flow pattern in many hydraulic phenomena especially intake structures is essential, because the rate of flow discharge as well as sediment input into the intake largely depends on the characteristics of this pattern. Predicting conditions of flow pattern will help the design engineers to design intakes with the highest discharge and lowest diversion sediment or to consider appropriate methods of controlling sediments entering the intakes in the equal hydraulic load. There are few studies conducted on three-dimensional flow pattern in lateral intakes and with the development of mathematical models and measurement tools, it is required to study more carefully. Studying the flow characteristics and sediment-flow interaction are among complex phenomena and sometimes with spending too much cost. Providing a physical model, using the experiences of experts, the application of mathematical models in flow simulation in one-, two- and three-dimensional flow patterns include methods that can be used in studying the flow patterns. Given the three-dimensional nature of flows in the nature, using the three-dimensional mathematical models in river engineering can help to solve technical challenges. Christodoulou [1] conducted experiments to obtain a criterion for the formation of a hydraulic jump in the combination of rectangular three branches flows. His analysis is stated based on the one-dimensional momentum equation. He presented the results of his work in a form that was divided into the ranges of hydraulic jump and lack of hydraulic jump. Shazy *et al*. [2], presented the dynamic model for sub critical flows analysis at the channels confluence. The model, using the momentum equation of motion and the law of conservation of mass in two control volume that have a common border and knowing information such as the downstream discharge and downstream depths, has the ability to calculate and estimate the upstream depth. The parameters used in this model were the shear forces between the two volume controls and the shear boundary friction force of the flow separation zone. Examination and the comparison between the experimental data and model

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predictions indicated the compliance between model predictions and the observations from the experiments. Weber and Greated [3] proposed the flow analysis at the place of channel reach and focused their studies on the upstream and downstream depths of the confluence. They considered different angles from the channels connecting angle with each other (δ) in their studies and effect the channels lateral wall curvature. Hager [4] examined the three branches flow while the upstream was changed into three branches and sub branches of sub critical flow and in downstream has changed into supercritical flow.

Emami [5] examined the hydraulic performance of the wastewater discharge system and energy dissipation of an embankment dam using FLOW 3D.

Ead and Rajaratnam [6] performed experimental studies on the hydraulic jump on corrugated bed. The experiments were done for Froude Number 4 to 10 and selected and studied the relative roughness amount t/Y1 between 0.25 to 0.5 where t is wave height and Y1 is water depth before jump and concluded that downstream depth required to make hydraulic jump on corrugated bed is smaller than classic hydraulic jump (smooth bed) and jump length is also half of the jump length in smooth beds. Yazdi *et al*. [7] studied the flow pattern in hydraulic jump stilling basin numerically using the VOF method. They examined the hydraulic jump which is one of the most important ways for flow energy dissipation in hydraulic engineering by using the FLOW 3D and showed that the software is able to predict the speed deep distribution in the hydraulic jump and in this test, RNG turbulence model compared with $k-\varepsilon$ offered better results. Kaman Bedast and Farajpour [8] simulated the flow in bottom intakes using FLOW 3D. Their results showed that the best slope for impoundment is 20 degrees and on the other hand, however the intake opening percentage increases, discharge ratio can also be increased. The flow intensity coefficient variation in different modes than the Froude number and the percentage of intake network opening will reduce the flow discharge coefficient.

MATERIALS AND METHODS

Gotvand regulatory dam is located in the northeast of Gotvand city on the Karun River. The dam which is an embankment one with gated concrete spillway is constructed in the south west of Iran in Khuzestan province with coordinates Eastern 40-48 and Northern 10-32. Gotvand intake which is located in the western flank of the Gotvand regulatory diversion dam includes 4 radial gates with a discharge of $92.5m^3/s$. Flow 3D is among the computational fluid dynamics software packages that has many applications for modeling the three-dimensional, complex steady and unsteady conditions with irregular geometry and shape. Another use of the software is hydraulic simulation of erosion and sedimentation issues as well as issues related to the transfer and dissemination phenomena in the environment. The advantages of Flow3D is its applicability than similar softwares, rapid implementation and design of boundaries and solid geometry and also lattice work, providing guide messages to make the simulation better, automatically selecting the best time intervals without defining primary time interval and other benefits. This software can display the instantaneous changes of different hydraulic parameters such as depth and velocity in different directions and at any desired point of the structure as a text or graphic file. In this study, to investigate the flow patterns in the upstream and downstream of lateral intake, Flow3D Version. 10.0.1 and model RNG were used that had high and acceptable accuracy. Comparison of the output characteristics of the hydraulic jump Flow 3d was done by empirical formula related to the hydraulic jump as follows.

$1 < Fr1 < 2.5 \rightarrow L_j = 3y_2Fr_1^{1/2}$ (1)

$2.5 < Fr1 < 4.5 \rightarrow L_j = 5(y_2 - y_1)$ (2)

$4.5 < Fr1 < 9 \rightarrow L_j = 6y_2$ (3)

In the above equations $Fr_1$is the Froude number before the hydraulic jump, L_j is the hydraulic jump length (m) and $y_2, y_1$are respectively the depth before and after the hydraulic jump [9].

For this purpose, first the shape of Gotvand intake was drawn by AutoCAD three-dimensionally and then was sent to FLOW 3D. Then by entering the hydraulic data related to Gotvand dam intake in Flow3D, we began to simulate the flow. Next, after ensuring the accuracy and precision of the mathematical model, we began further researches and obtaining the best mode of intake gate opening to create the minimum flow turbulence and maximum discharge. In this study, to investigate the flow pattern in the upstream and downstream, the maximum discharge $84.5m^3/s$ in the four modes of the gate opening ($1,1.6,2.25,3.15m$) was considered.

Analysis and Discussion:

After presenting the above explanations, this section examines the results. The study included 4 scenarios that for analysing these scenarios, the software analyzed for a total of 10 times that 6 times was unacceptable. To calibrate the results one meter intake gate opening height in discharge $84.5m^3/s$ was compared with Manning equation. To improve the accuracy of output results, it was determined that to conduct meshing in a separate section that a total of 381,520 cells were used and formed for Gotvand intake (Figure 1).

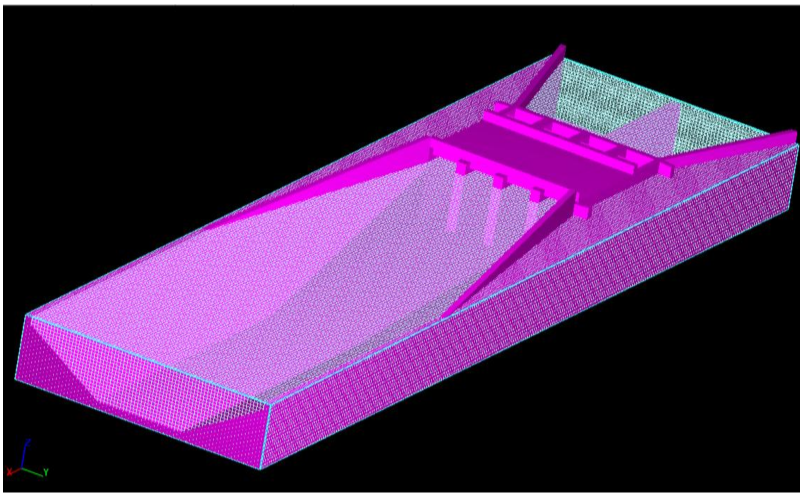

Fig 1: A view of meshing done in the software.

In this study, to calibrate the mathematical model with reality, the results of Manning equation were used.

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

To this end, in a point with a distance of $35m$ from the center of Gotvand intake and in the level of $196.52m$, for discharge $84.5m^3/s$ the flow rate was $2.4m/s$, that was more consistent with the speed $2.2m/s$ obtained from the Manning's (Table 1).

Table 1: Results of model calibration.

Title	Discharge (CMS)	measurement velocity from Manning's equation (m/s)	Measurement speed in Mathematical Model (m/s)	Error percent
Gotvand intake	84.5	2.2	2.4	9

After calibrating the software and ensuring the accuracy of the results and outputs, the data was examined. After running the software and analyzing the mathematical model for Gotvand intake with different opening heights and for maximum discharge $84.5m^3/s$, the results were provided. Figures 2 to 5 show the results of the simulation of flow through the Gotvand intake gate beneath by software.

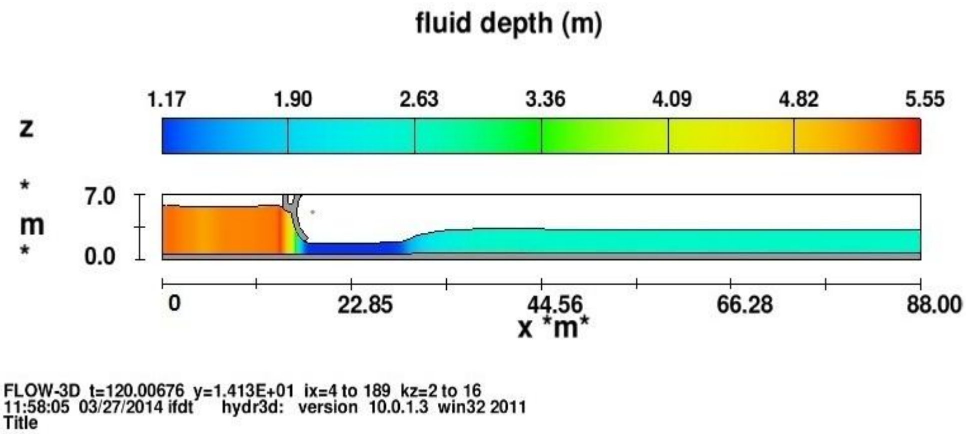

Fig. 2: water depth at 1 meter opening of Gotvand intake gate.

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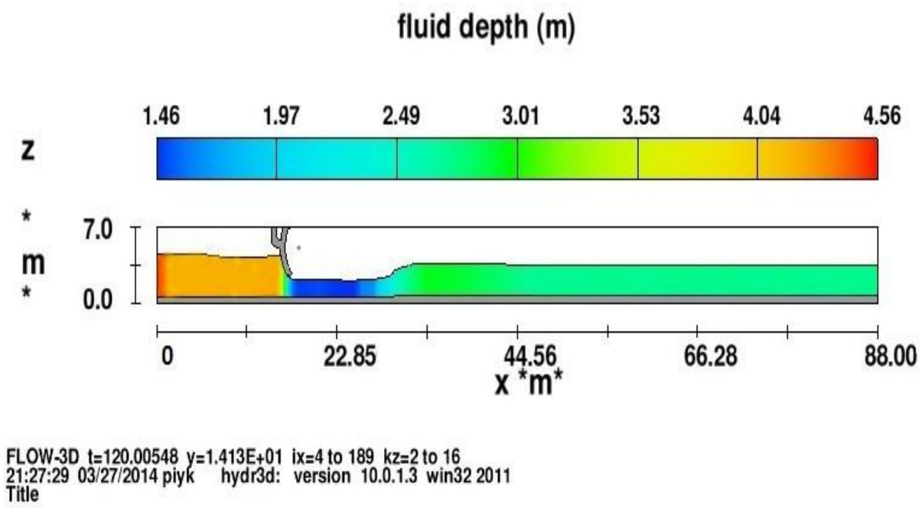

Fig. 3: Water depth at 1.6 meters of opening in Gotvand intake gate.

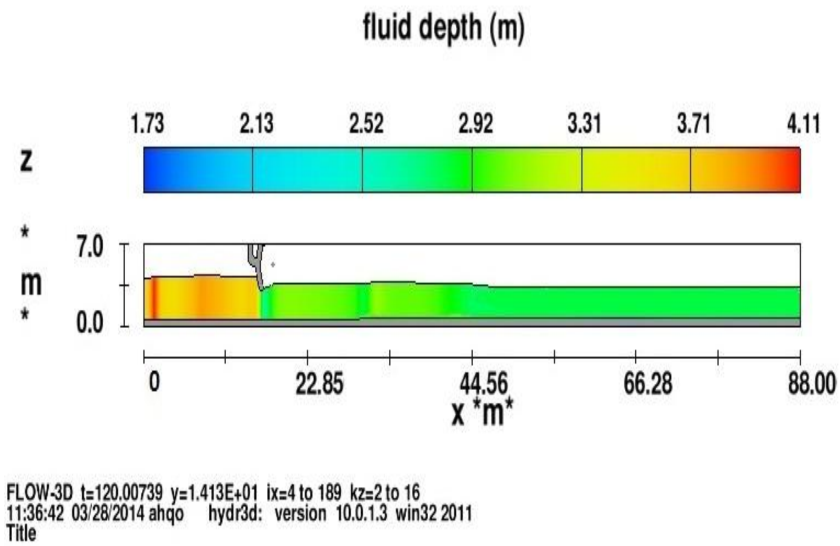

Fig. 4: Water depth at 2.25 m opening of Gotvand intake gate.

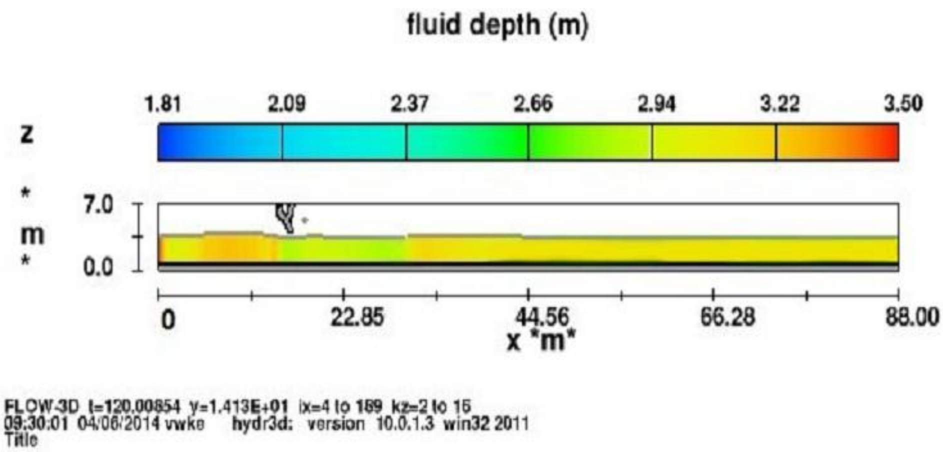

Fig. 5: Water depth at 3.15 m of opening of Gotvand intake gate.

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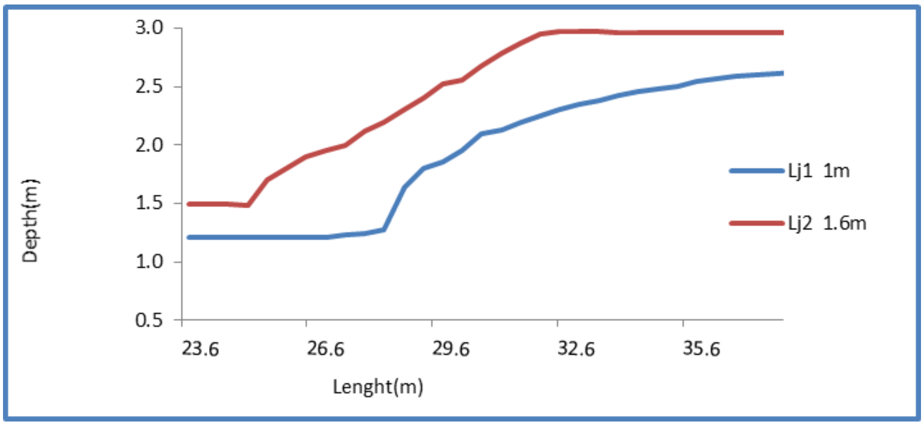

Fig. 6: Comparison of the jump length in the openings 1m, 1.6m.

The results showed that at the opening height 3.15m, water flows pass through it without collision to the intake gate (Figure 5), and this indicates that the discharge designed for the intake is suitable. Also, in the height of openings 2.25m, 3.15m no hydraulic jump occurs (Figure 4 and 5). By comparing the length of the hydraulic jump in the intakes with the openings 1m, 1.6m (Figure 6), it is concluded that with increasing intake opening height, due to the speed reduction, the hydraulic jump length is reduced.

Table 2: Hydraulic jump characteristics in the Gotvand intake .

$h(m)$	$y_1(m)$	$y_2(m)$	F_r	$V_{max}(\frac{m}{s})$	$L_{iMod}(m)$	$L_{IEq}(m)$
1	1.21	2.7	2.3	7.44	13.07	12.28
1.6	1.49	2.98	1.79	6.8	11.21	11.96
2.2		No jump				
3.1		No jump				

h =Gate opening height, y_1 =Water depth before the jump, y_2 =Water depth after the jump, F_r = Froude number, V_{max}= Maximum speed, L_{iMod} =Jump length in model, L_{IEq}= Hydraulic jump length from the equation**.**

To investigate the effect of average velocity and flow Froude number on hydraulic jump length, output results from the software for the Froude number and velocity in four different modes of opening (1 m, 1.6 m, 2.25 m and 3.15 m) at the discharge 84.5 m2/s are shown in Figures 7 and 8. Comparison of the average speed in four modes of intake opening shows that by increasing the height of the gate opening, speed decreases. Figure (7)

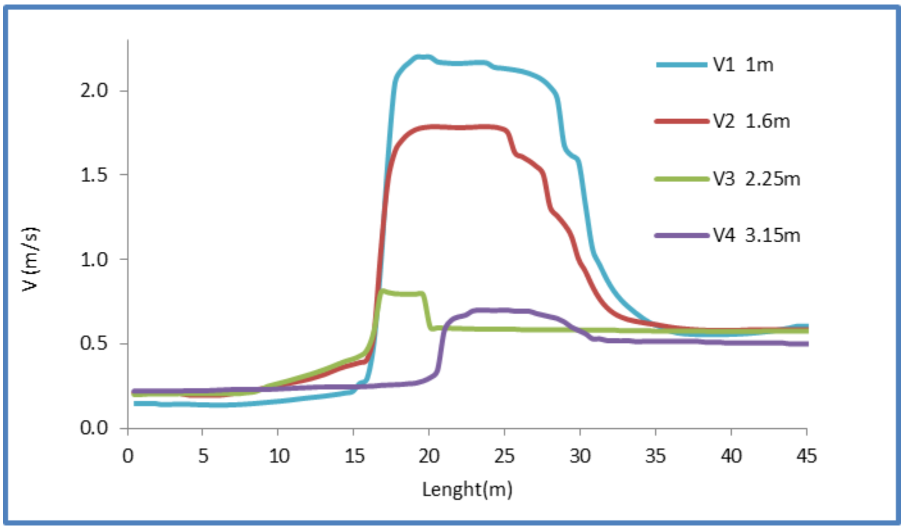

Fig. 7: Comparison of the average speed in four modes of opening in the intake gate.

According to Figure 8, by increasing Froude number in gate opening due to the increased flow rate through the jump horizontal length increases.

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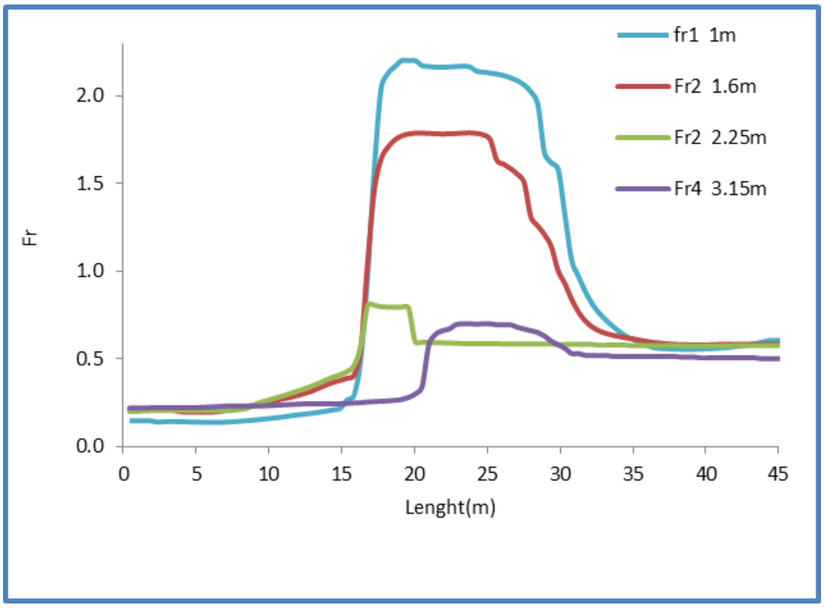

Fig. 8: Comparison of the Froude number in four modes of opening of intake gate.

As can be seen in Figure 8, by increasing gates' opening, Froude number decreases, and this is because with increasing Froude number flow rate increases, also in all the openings by increasing Froude number jump length increases. Because the flow Froude number is directly related to the average speed and on the other hand, the flow rate has a direct linear relationship with discharge, so increasing each of these parameters increase two other parameters and decreasing each of them decreases the two other parameters. Results represent a true and significant relationship with the mathematical equations and software output data. All output parameters of the software represent the direct effect of speed in the horizontal line on the jump length and it shows the accuracy of the analysis.

Conclusions:

In this study, the flow pattern in the upstream and downstream of the Gotvand intake was simulated using the Flow 3d. The results showed that the best mode of gates' opening for Gotvand intake is in the height of $2.25m$ because at this height of opening no hydraulic jump and energy disruptions occur. The results also showed that in the opening $3.15m$, water flow was not collided to the gate and this indicates that the discharge capacity designed for the intake is suitable. The results showed that the maximum length of the jump ($L_{jmax} = 13.07m$) in the Gotvand intake occurs at the height of $1m$ of the gate opening and lowest jump length at ($L_{jmin} = 11.21m$) at $1.6m$ of gate opening height. The results showed that the maximum value of the Froude number ($F_{rmax} = 2.3$) occurs at the gate opening height $1m$. Generally, with increasing Froude number in each of the openings of the intake gate, the hydraulic jump increases.

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