The Comparison of Modeling Profile of Velocity Inside Turbidity Currents Using FLOW-3D and Fluent Software

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Abstract—Turbidity currents are gravity currents in which the difference of density or weight difference between two fluids is because of suspended sediments. Considering sedimentation of turbidity currents in dams’ reservoirs, hydrodynamic recognition of these currents will have great effect on increasing useful life of dams. So identifying hydrodynamic and characteristics of turbidity currents is very important in different fields. Using FLOW-3D and Fluent software velocity in the body of turbidity current has been modeled and compared to each other in this paper. The obtained results of numerical models of velocity profile in the body in inner regions (between bed toll maximum velocity) and in outer region (between the maximum velocities until the velocity gets almost zero) have relatively good compliance.

Keywords—Turbidity Currents, Hydrodynamic, Velocity Profile, FLOW-3D, Fluent

I. INTRODUCTION

Velocity distribution vertically in turbidity currents has important and main role in distributing sediments in the current and therefore it affects many other aspects of sedimentation [1]. Sedimentation in river bends has been considered by Ketabdar and Hamedi [2] and Ketabdar [3] experimentally and numerically respectively. Sedimentation and velocity changes may create different types of damages such as erosion, abrasion, cavitation, and some instability, which are extensively reported for marine structures [4-6]. One of measuring methods of these currents is numerical modeling, implementing and executing numerical models is very less expensive than experimental ones and their function isn’t limited to only a specific sample. Such a modeling has been applied in the other fields and compensate more of the effort for experimental works like to work carried out by Darvish et al. [7-11]. Moreover, maneuverability on the channel geometry is very high in numerical models and channel can be simulated with those very real dimensions of that. As result, all characteristics of current can be simultaneously simulated in these types of models but the biggest weakness of these models is lack of considering all effective parameters on nature. In another word, only main effective factors on flows are modeled in these models. On the other hand, in numerical models, there might be errors while environment boundaries are implemented, dominant equations are prepared for solution using the method in the model as well as numerical solving of obtained equations. Each one of these errors can be reduced through some measures. However, these errors will never eliminate. Therefore, obtained answers from model, in initial using that, are better to be analyzed and controlled with experimental results to specify the weaknesses and strengths of model. Hamedi et al. [12][13] considered the energy loss experimentally then used the numerical methods to simulate the flow to show the capabilities of this kind of method. In fact, numerical method completes other methods well but it can replace them because a theory and natural affairs and experimental experiments will be always required.

In this paper, a numerical model of non-conservative turbidity currents is sought to be found using Flow 3-D and Fluent software. Numerical modeling in Flow 3-D software was conducted through VOF method and modeling in Fluent software was conducted in two phases through Euler-Lagrange method. In order to verify numerical modeling in determining hydraulic parameters of turbidity currents such as velocity profiles in the body of turbidity current, these two models were compared with each other. How turbidity currents move with numerical modeling and its body and head parts have been shown in figures 1 and 2. The movement of head and body of a permanent turbidity current has been clearly proposed in the figure and it is seen that the height of body is almost fixed but the head of current has variable shape and height along the path of channel.

II. THEORETICAL PRINCIPLES

Dominant equations on fluid current include continuity equations and size of movement. Continuity equation of current is obtained from the law of conservation of mass and through writing the equation of mass equilibrium for a fluid element. This equation is generally written as follows:
In which $V_F$ is the ratio of fluid volume passing an element to the total volume of element and $\rho$ is fluid density. Velocity components ($u$, $v$, $w$) are in directions of ($x$, $y$, $z$). $R$ and $\xi$ are related to the type of coordinate system and Cartesian coordinates are $R=1$ and $\xi=0$. Navier-Stokes equations of fluid with velocity components ($u$, $v$, $w$) in 3 dimensional coordinates are shown as below:

$$V_F \frac{\partial \rho}{\partial t} + \frac{\partial}{\partial x} (\rho u A_x) + \frac{\partial}{\partial y} (\rho u A_y) + \frac{\partial}{\partial z} (\rho u A_z) + \frac{\partial}{\partial x} (\rho v A_x) + \frac{\partial}{\partial y} (\rho v A_y) + \frac{\partial}{\partial z} (\rho v A_z) + \frac{\partial}{\partial x} (\rho w A_x) + \frac{\partial}{\partial y} (\rho w A_y) + \frac{\partial}{\partial z} (\rho w A_z) = 0 \quad (1)$$

$$\frac{\partial u}{\partial t} + V_F \left( u \frac{\partial u}{\partial x} + w \frac{\partial u}{\partial y} + v \frac{\partial u}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial p}{\partial x} + G_x + f_x \quad (2)$$

$$\frac{\partial v}{\partial t} + V_F \left( u \frac{\partial v}{\partial x} + w \frac{\partial v}{\partial y} + v \frac{\partial v}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial p}{\partial y} + G_y + f_y \quad (3)$$

$$\frac{\partial w}{\partial t} + V_F \left( u \frac{\partial w}{\partial x} + w \frac{\partial w}{\partial y} + v \frac{\partial w}{\partial z} \right) = -\frac{1}{\rho} \frac{\partial p}{\partial z} + G_z + f_z \quad (4)$$

In these equations, $(G_x, G_y$ and $G_z)$ are terms of mass acceleration, $(f_x, f_y$ and $f_z)$ are terms of viscose acceleration [14].

III. INITIAL CONDITIONS

Numerical modeling in this paper will be conducted for a gravity current containing particles in a channel of 12-meter length and 75-centimeter height. The concentration of particles is 0.5 percent and flow rate will be about 20 liters on minute. The slope of channel is also 2 percent. Modeling was done two dimensionally. Turbidity current with fixed flow rate gets into standing water in the channel from 1 centimeter part below the valve and when it reaches the end of channel, modeling will be stopped. Then the velocity of turbidity current is calculated in middle depths of channel transversely.

Initial conditions for modeling have been shown in table 1.

Considering table 1, $C_0$ is initial concentration, $q_0$ is density fluid inflow rate, $U_0$ is the velocity of inflow, $b_0$ and $h_0$ are respectively the width and height of input valve, $g_0$ is reduced gravity velocity, $B_0$ is input floating flux, $R_i_0$ is Reynolds number of inflow, $R_i_0$ is initial Richardson number of flow and $Fr_0$ is initial Froude number of flow.

The velocity of reduced gravity ($g'_0$) and input floating flux (B0) and initial Richardson number ($R_i_0$) are:

$$g'_0 = \frac{g - g_0}{g_0} \quad (5)$$

$$B_0 = b_0 h_0 U_0 g'_0 \quad (6)$$

$$R_i_0 = \frac{g'_0 h_0 \cos \theta}{U_0^2} = \frac{1}{Fr_0^2} \quad (7)$$

IV. NUMERICAL SOLUTION OF EQUATIONS THROUGH FLOW 3D SOFTWARE

Boundary conditions are introduced in numerical model in software Flow 3D as below:

1- The velocity of density inflow under the valve into the channel (obtained by dividing inflow rate on input section level)
2- The concentration of density flow that is obtained from multiplying the percentage of volume concentration in sediments particles density. The density of sediments particles is 2648 kg/m³.

<table>
<thead>
<tr>
<th>RUN.NO</th>
<th>Slope (%)</th>
<th>C₀ (gr/cm³)</th>
<th>Q₀ (lit/min)</th>
<th>b₀ (cm)</th>
<th>h₀ (cm)</th>
<th>U₀ (cm/s)</th>
<th>g'₀ (cm/s²)</th>
<th>B₀ (Cm⁴/s³)</th>
<th>Re₀</th>
<th>Ri₀</th>
<th>Fr₀'</th>
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</thead>
<tbody>
<tr>
<td>No.1</td>
<td>2%</td>
<td>0.005</td>
<td>20</td>
<td>20</td>
<td>1</td>
<td>16.67</td>
<td>3.0618</td>
<td>51.03</td>
<td>1618.2</td>
<td>0.0110</td>
<td>9.525</td>
</tr>
</tbody>
</table>

Figure 3. The geometry and boundary conditions of current

Two fluids have been used for modeling that one is standing water with density of 998.53 kg/m³ and viscosity of 1.014*10⁻⁵ and the other the flow of density which is located under stagnant water.

Considering previous experiences and investigated turbulence models for turbidity currents, in order to simulate experimental turbidity current, RNG turbulence models and scour model have been used in the current research [15].

V. NUMERICAL SOLUTION OF EQUATIONS THROUGH FLUENT SOFTWARE

Fluent is strong software in the field of CFD that has been written with programming language of C and uses all the capability and flexibility of this language. Also, Zeidi et al. [16-19] generated an Eulerian-Lagrangian approach for tracking bubble besides developing a comprehensive model inside Ansys-Fluid, which had been very helpful to set up the current geometry and mesh topology.

Continuity and Navier-Stokes equations are used in analyzing the current. In case the current is turbulent then dominant equations turn to Reynolds ones and one-equation, two-equation, five or six-equation models are used for determining eddy viscosity that user determines the type of model [20]. Fluent converts dominant equations to algebraic

equations through the method of finite volumes and then solve them [21].

Considering that Fluent software doesn’t generate network itself and the network should be generated in another software, Fluent is capable of reading mesh from other software such as Gambit, Geomesh and ANSYS. In this research in first step, the shape of problem is drawn in AutoCAD software and in the second step, meshing was formed on general geometry in Gambit software [22], meshing is non-uniformly and rectangular. Rectangular mesh has been used by Baqersad et al.[23] and Fesharaki and Hamedi [24] previously. Then the type of the boundaries of solution zone such as wall, input and output were specified, generated mesh is read in Fluent software and controlled in this software based on the research work of Hamedi et al. and Hamedi and Ketabdar [25][26] in case of probable problems such as negative volumes.

Geometry and boundary conditions of current have been represented in figure 3.

VI. COMPARING THE RESULTS OF MODELING

A density flow consists of two main and important parts of head and body. The body of density flow is semi-uniform part of flow in which flow is almost permanent in that area. In another word, time and place changes of velocity in the body of flow are almost trivial. According to conducted researches in
past, a velocity profile in the body consists of two inner and outer regions that are separated from each other by maximum velocity $U_m$ that is often defined as the nose of head of turbidity current. Inner region or that very gradient wall area has a positive velocity and turbulence is generated caused by floor roughness. The sediments are sucked from floor in this region and velocity distribution in this region is a logarithmic distribution. The thickness of this area is less than half thickness of external region. A longitudinal velocity profile has been proposed in figure 4. The velocity field, also, has been considered in vortex flow by Sarkardeh et al. [27].

Outer region of gradient has negative velocity that this negative gradient is because of backward flow of environmental fluid. Turbulence in this region is obtained from mixing with upper stagnant fluid. Velocity distribution in this area is a normal distribution of Gasyn. The results show that velocities near shear layer, between density and stagnant fluid are less than middle scale of flow while a part of existing suspended sediments in density flow is defused into upper stagnant fluid and mix with it and therefore cause clouding of the clear water and move with it as backward flow while it isn’t a part of density flow [1].

![Figure 4. Longitudinal velocity type profile with specific heights in density flow [1]](image)

![Figure 5. The comparison of numerical modeling of velocity profile in body through Fluent and Flow 3D software for slope of 2%, concentration of 0.5% and flow rate of 20 liters on minute](image)

In all three levels of numerical modeling, density flow with specific flow rate and concentration enters into the channel from 1 centimeter below the valve, when the flow reaches to the end of channel, modeling will be stopped and velocity profiles in middle depths of channel are measured transversely and compared with each other.

To compare numerical solution, experimental results conducted by Hosseini et al that had been accomplished in
Center of Energy Pole of Sharif University were used. As it can be seen in figure above, the results of numerical modeling have good compliance with the experimental results.

Calculated velocity profiles due to central line of channel are measured to determine the average height (H) and velocity (U) of layer (depth) in each section and used by the following equations.

\[ UH = \int_{0}^{\infty} u(z)dz = \int_{0}^{H} u(z)dz \]  \hspace{1cm} (8)

\[ U^2H = \int_{0}^{\infty} u^2(z)dz = \int_{0}^{H} u^2(z)dz \]  \hspace{1cm} (9)

In which, \( u(z) \) is average longitudinal velocity of flow at the distance of \( z \) from bed and \( H \) is the height of whole flow and place where the velocity of flow gets almost zero. The values of whole flow height are \( H \), flow maximum velocity is \( U_{\text{max}} \) and the similar height of the maximum velocity is \( H_{\text{m}} \) which have been shown in table 2 and compared with the results of two modeling. Furthermore, It is recommended to use artificial intelligence and compare the results with numerical simulation [28].

<table>
<thead>
<tr>
<th>Description</th>
<th>Type of comparison</th>
<th>(Experiment)</th>
<th>(Flow 3D)</th>
<th>Error percentage</th>
<th>(FLUENT)</th>
<th>Error percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2C5Q20</td>
<td>Hit(cm)</td>
<td>21.7</td>
<td>19.5</td>
<td>-10.14</td>
<td>19.67</td>
<td>-9.35</td>
</tr>
<tr>
<td></td>
<td>U_{\text{max}}(cm/s)</td>
<td>4.1</td>
<td>4.59</td>
<td>-11.95</td>
<td>4.15</td>
<td>1.22</td>
</tr>
<tr>
<td></td>
<td>H_{\text{m}}(cm)</td>
<td>7.7</td>
<td>6.65</td>
<td>-13.64</td>
<td>5.7</td>
<td>-25.97</td>
</tr>
</tbody>
</table>

TABLE II. COMPARING THE RESULTS OF WHOLE FLOW HEIGHT, MAXIMUM VELOCITY AND ITS SIMILAR HEIGHT

VII. CONCLUSION

The velocity in the body of turbidity current has been modeled through Fluent and Flow 3D software and then compared to each other. Hydrodynamic quantities of average flow including height, velocity, maximum velocity and corresponding height with that by the help of obtained velocity profiles were calculated and compared with each other in numerical models.

Through the comparison of velocity profiles between Fluent and Flow 3D software in the body of density flows in a common experiment, relatively good compliance can be seen.

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