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3D-Numerical Simulation of the Flow in Pool and Weir Fishways

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Summary. Construction of dams and hydraulic structures across the river change the pattern of fish migration upstream to spawning areas, preventing their free movement and affects their reproduction and consequently declining their population. Fish passages are kind of energy dissipator structures that help migratory fish to overcome obstacles in their way and lead them toward safe havens for spawning. One of the first and common fish passages are pool-and-weir fishways which consist of a channel with several weirs with a specific slope that have been formed at regular intervals. Flow of the water has to pass from one pool to another pool passing the weirs. By placing submerged orifices, these weirs can also ease the migration for fishes which are not able to jump over the weirs. In this study, three-dimensional numerical modeling of this type of fishways has been investigated using commercial CFD code, FLUENT. The idea of this investigation is extracting important design considerations for fish passages. The results showed that standard K-ε model and the rectangular mesh type are appropriate assumption in order to compute turbulence and flow rotation in pools in comparison with other turbulence models. Numerical results showed that they are in good agreement with those of experimental investigations and required compliance exists between these two data sets. Finally, by studying turbulence and velocity profiles, safe passages in pool and also resting zones with very low speed were extracted which can help better designs.

1 INTRODUCTION

The Increase of human knowledge in recent years has caused the use of natural resources and pressure on our environment to be increased significantly. Construction of dams and obstacles such as bridges on rivers has changed the river environment and aquatic life. Therefore, different fish species which have to migrate upstream for their survival and reproduction face great problems. To solve this problem fishways as a special type of hydraulic structures are used to overcome the migration barriers. Hydraulic conditions of fishways should be managed according with fish ability and type in a manner to make them capable of passing through these structures. Fishways should be designed based on the size, number and fish speed to prevent any delay for their migration. Fishways may be classified as Vertical slot, Pool-weir, Denil, and Culvert fishways (Yagci, 2009). These fishways have major differences in terms of their design parameters such as geometry, energy dissipation rate and providing enough space for migration. The first three types are similar in having pools in their structures. According to Clay (1995), flow pattern in fishway has an important influence on fish attraction. In addition to flow velocity and depth that affect the fish swimming capability, turbulence intensity is also effective and must be specified. Flow patterns and turbulence in fishways provide suitable swimming conditions for some specific fish species (Yagci, 2009).

Rajaratnam et al. (1986) extracted a linear relationship between dimensionless discharge and relative depth of flow by experimental studies on vertical slot fishway. Alvarez-vazquez et al. (2008) presented a mathematical formulation of an optimal design problem for a vertical slot fishway. Rajaratnam et al. (1988), Kim (2001), Ead et al. (2004), Heimerl et al. (2008), Yagci (2009) and Atsushi (2010) have carried out experimental and numerical studies on the pool and weir fishway to explain its flow pattern. In this study by numerical modeling of an experimental pool and weir fishway and comparison of results, the optimum turbulence model and mesh type are presented.

2 POOL AND WEIR FISHWAY

This type of fishway has a channel with weirs at regular intervals with a downward slope. The water passes over the weirs from the upstream pool to the lower pool (Figure 1). This fishway has two objectives, i.e., to ensure adequate dissipation of the energy of water, with no carryover of energy from one pool to another and to offer resting areas for fish (Larinier and Marmulla, 2004). Weirs may also be associated with one or more notches.

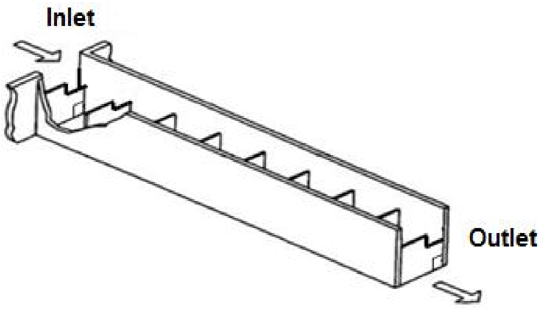

Figure 1: Pool and weir fishway

Pool and weir fishways are usually combined, i.e., either flow passes over the notches or through submerged orifices or both. From a pool to the lower pool fish jumps over weirs and notches or swims through orifices. This type of fishway is suitable for fish with high swimming ability. Flow in pool and weir fishways is formed in tow forms: plunging and streaming. In streaming form, a surface flow is formed over the weir crest that covers water level between the two pools (Figure 2a). In plunging flow, water level in next pool is lower than water level over weir crest (Figure 2b). Flow pattern changes from streaming to plunging form with increase of discharge. Rajaratnam et al. (1988) presented criteria for transition from plunging to streaming flow.

Figure 2a: Plunging flow in pool and weir fishway

Figure 2b: Streaming flow in pool and weir fishway

3 EXPERIMENTAL MODEL OF YAGCI (2009)

In this study, experimental setup of Yagci (2009) has been used for numerical simulation. These experiments were performed in a 0.98 m width, 0.85 m height and 26 m length flume. The base was made of concrete with Plexiglas sides. Eight pools were formed for the tests: a head tank receiving the water from an upstream reservoir, six active pools, and a tail tank. The bed slope of the fishway was 7%. Three-dimensional velocity measurements in planes were performed in the fifth pool to determine the velocity and turbulence pattern for each configuration in different layers (Yagci 2009). The pool was 0.7 m in length (Measurement stations located at 0.02 m along the length) and the height of weir was 0.35m.

Yagci (2009) maintained the size of orifice constant in his experiments with three different sizes of notch (configuration 1, 2 and 3) and concluded that configuration 3 provides relatively reasonable velocity pattern for the total discharge of 35.4 l/s compared to configurations 1 and 2 (Figure 3).

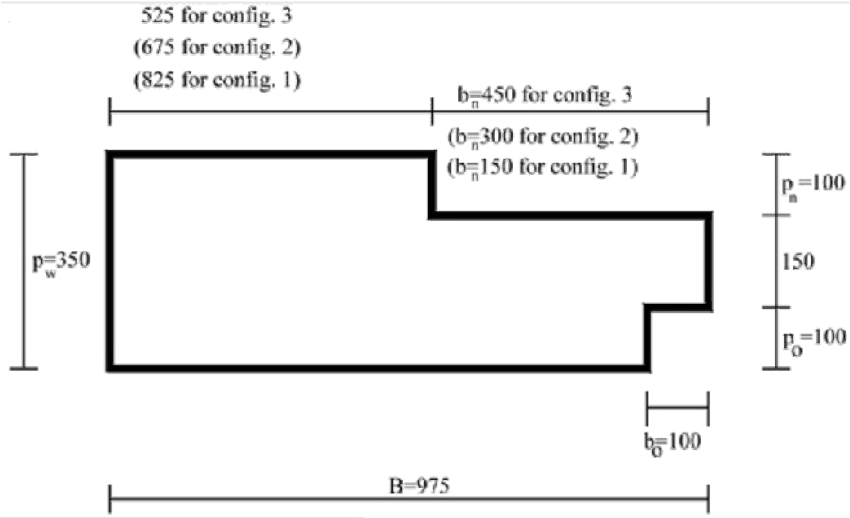

Figure 3: Different configurations of experimental model

4 NUMERICAL SIMULATION

To choose optimum turbulence model and mesh type, two different mesh types, quadratic and triangular, were generated for fifth pool of Yagci model with 5 different turbulence models (k-ε standard, k-ε realizable, k-ε RNG, large eddy simulation and Reynolds Stress). At first to choose optimum turbulence model numerical simulation was carried out with rectangular mesh and those 5 turbulence models. Optimum mesh sizes were found to be: $\Delta x = 0.005\,m$, $\Delta y = 0.004\,m$, $\Delta z = 0.01 m$ for the smallest cell.

To compute input discharges to the notch and orifice, dimensionless discharge, Q_*,was calculated using Equation 1 (Rajaratnam et al. 1986):

$$Q_* = \frac{Q_t}{\sqrt{g s_0 b_m^5}} \tag{1}$$

Where Q_t (discharge of orifice and notch) is the total discharge and s_0 is the slope of fishway, g is the acceleration due to gravity and b_m is the characteristic width of the active flow area as given in Equation 2:

$$b_m = \frac{b_o + b_n}{2} \tag{2}$$

Where b_o and b_n are orifice and notch width respectively. Then the relationship between total discharge Q_t and dimensionless discharge was obtained from Equation 3 by regression relationship between y_0, b_m and Q_* presented by Yagci (2009):

$$Q_t = \frac{\left[\sqrt{g s_0 b_m^5}\,(\frac{y_0}{b_m} - 0.731)\right]}{0.25} \tag{3}$$

where y_0 is average depth in pool. After computation of total discharge and notch, Q_n, and orifice discharge, Q_o , using Equation 4 and 5 presented by Yagci (2009), inlet velocities were calculated based on size of notch and orifice, 0.525 m/s and 0.75 m/s respectively.

$$Q_o = -0.006Q_t^2 + 0.456Q_t \tag{4}$$

$$Q_n = Q_t - Q_o \tag{5}$$

Numerical velocities and flow patterns were extracted for different layers. Numerical results of different simulations were compared with experimental results and due to less difference and more accommodation, Standard k-e turbulence model was selected (Figures 4a and 5b).

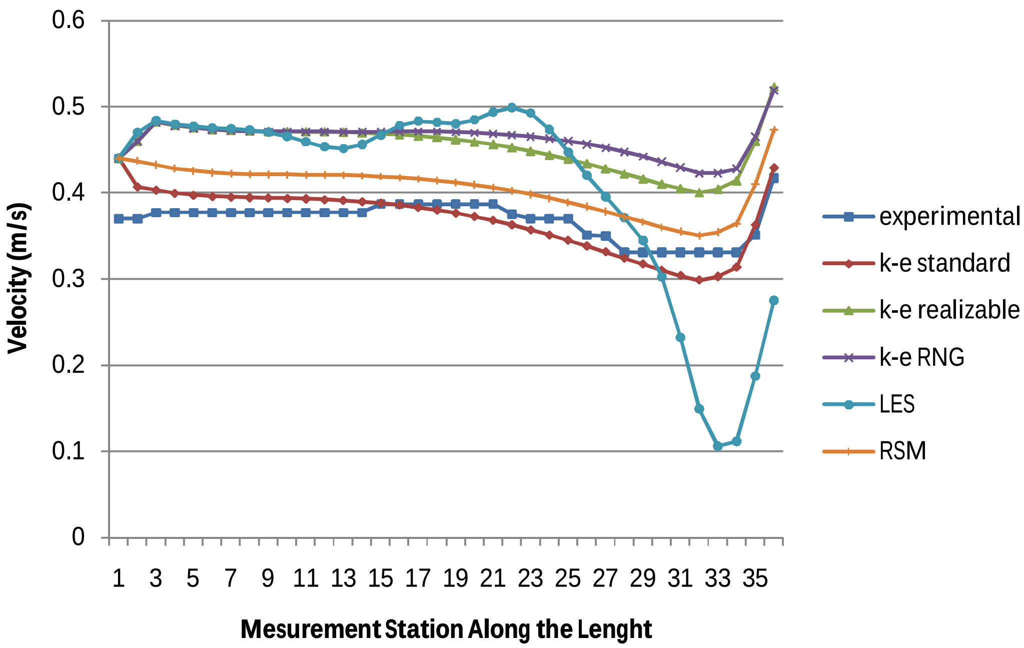

Figure 4a: Velocity comparison along the notch flow

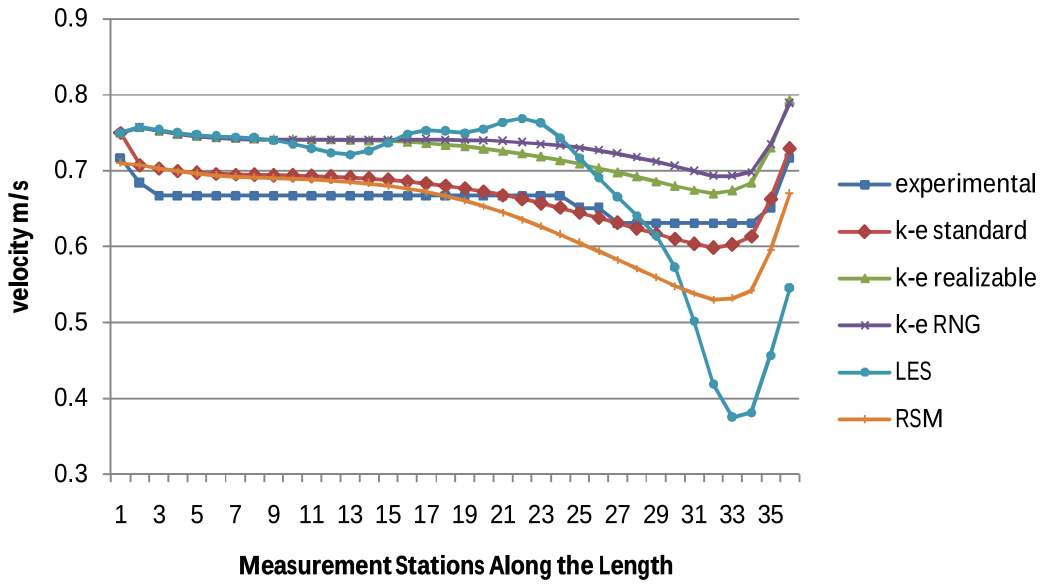

Figure 4b: Velocity comparison along the orifice flow

After choosing the optimum turbulence model, to choose optimum mesh type numerical simulation was performed with triangular mesh type and the optimum turbulence model (Standard k-ε). The volume of the smallest cell was: 2.61*e-7 m^3.

The solution and boundary conditions were generated as same as the last section (choosing the optimum turbulence model). The results showed that the rectangular mesh type has more accommodation with the experimental results compared with the triangular mesh type. It can be showed in figures 5a and 5b that the results of the triangular mesh type has more differences with the experimental results. So the rectangular mesh type was selected as the optimum mesh type.

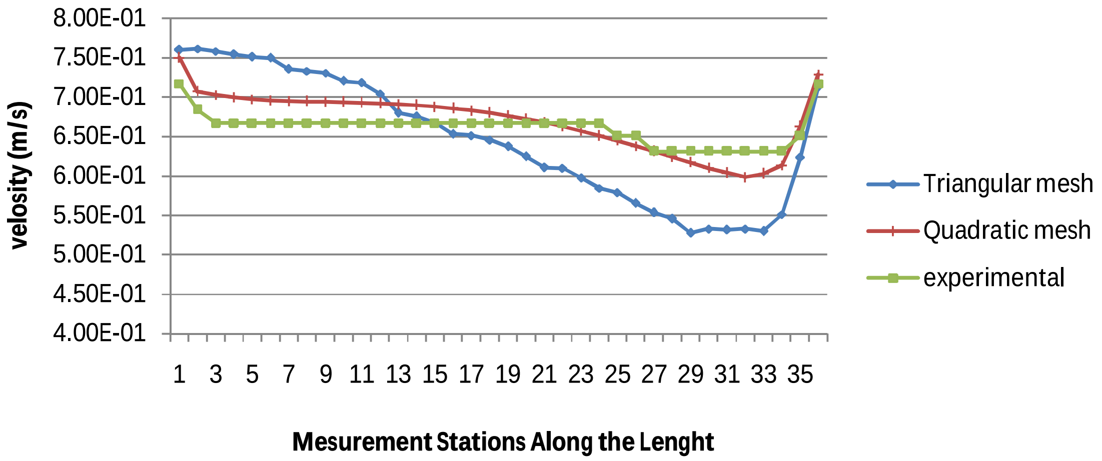

Figure 5a: Velocity comparison along the orifice flow for different mesh types

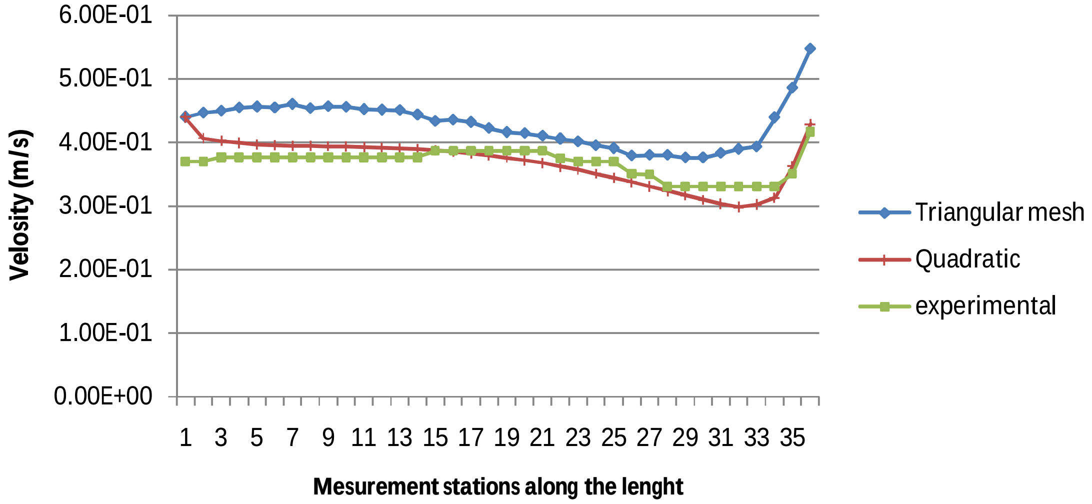

Figure 5b: Velocity comparison along the notch flow for different mesh types

The investigation of numerical results showed that two different flow regions can be observed in different measured layers: a primary flow region that includes high speeds and very small rotation and a recirculation region that includes low speeds (Figures 6a and 6b).

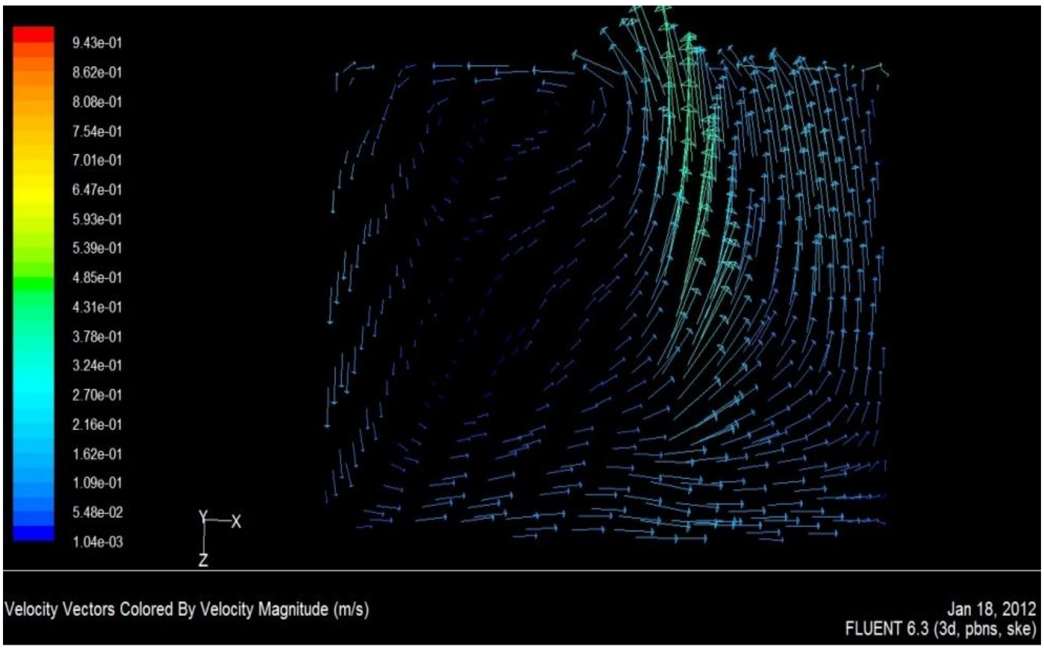

Figure 6a: Velocity vectors in the plane which intersects the notches

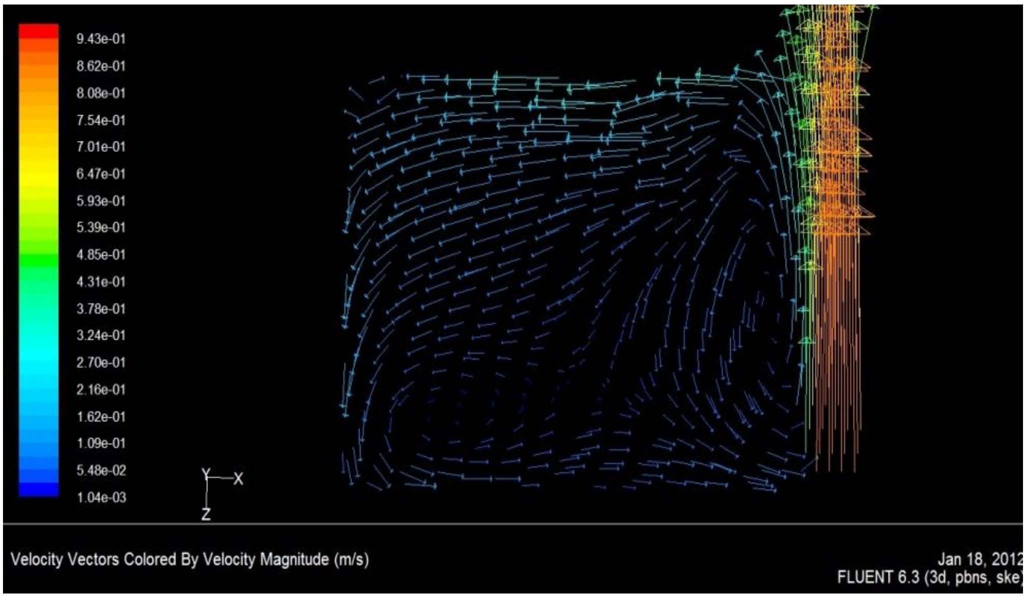

Figure 6b: Velocity vectors in the plane which intersects the orifices

To show the longitudinal profiles of the flow, velocity contours on Y-Z plane are presented in Figure 7. In longitudinal profiles of velocity, 3 flow regions can be observed: First the orifice flow region. The second one is the flow from the notch that is formed as streaming flow and its velocity is less than the first region. Third region is placed between the first and second one and its velocity is obviously less than two other layers.

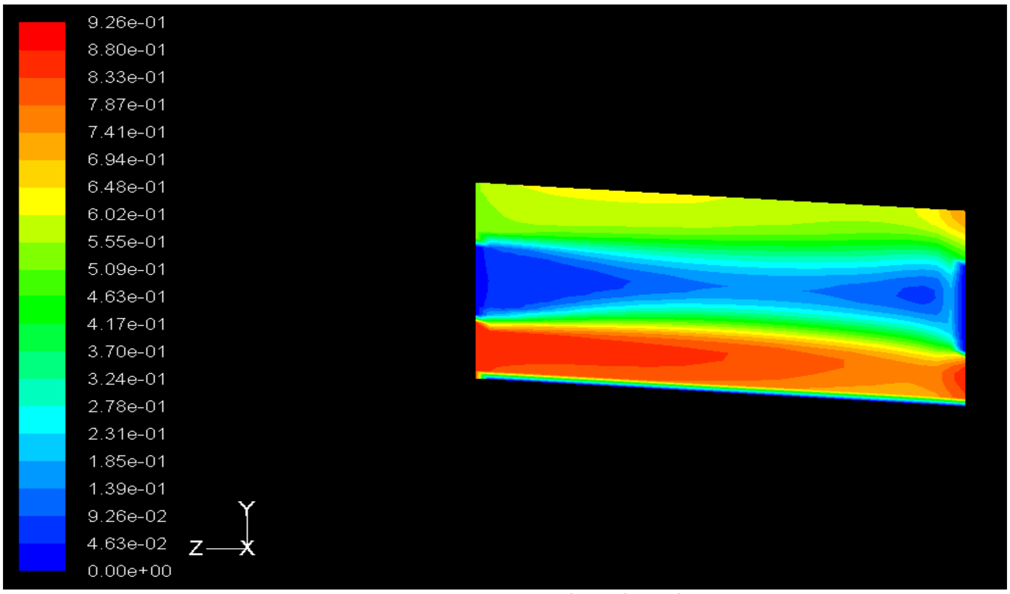

Figure 7: Longitudinal profile of the flow

It should be noted that streaming flow is observable in a plane far from the orifice and in a section that orifice is not visible (Figure 8).

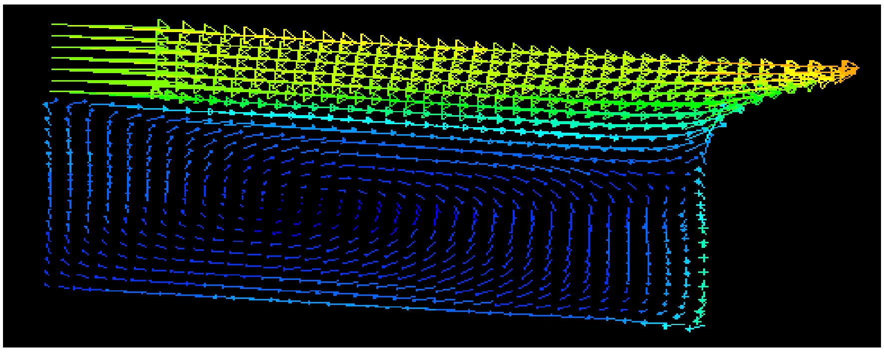

Figure 8: Longitudinal profile of the flow in a plane far from the orifice

5 CONCLUSION

In this study experimental fishway results of Yagci (2009) are numerically simulated.

- The selected optimum turbulence model for numerical simulation of pool and weir is Standard k-ε.
- The selected optimum mesh type is rectangular mesh type.
- Two different flow regions can be observed in velocity contours: primary flow region and recirculation flow region.
- Three different flow region can be observed in longitudinal profile of flow that the third region located between the first and second is suitable for fish resting.

According to Yagci 2009, the scale of this Freudian model is 2.65, so with this scale real dimensions of model would be: width of notch 1.2 m, dimensions of orifice 0.27*0.27 m which are reasonable according to average length and height of local fish, and they can swim over the notch and through the orifice safely without unfavorable stresses.

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