Journal of Research in Ecology

An International Scientific Research Journal

Original research

Numerical simulation of the inlet sedimentation rate to lateral intakes and comparison with experimental results

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ABSTRACT:

Intakes are for the most part utilized as a part of water dispersion systems, irrigation channels, sewage systems, water/wastewater treatment offices, contribution to power generation facilities and so on. Because of the stream multifaceted nature and furthermore the impacts of scale, physical models can not exclusively give a reasonable comprehension of the material science administering the stream field and it is important to study this marvel numerically alongside field and experimental trials. Absence of inlet sediment control to admission because of sediment transport to water system channels and offices make troubles for various parts. In this review, the flow numerical simulation has been performed in the immediate way of rectangular channel utilizing SSIIM programming and k-ω turbulence model. The impacts of the geometric and water driven parameters on stream partition zones are explored. At that point, for examination of the sedimentation, impact of deviation edges of 45 to 90 degree and release proportion on the proportion of channel residue to admission is stimulated. Numerical outcomes were contrasted and the trial; and a decent understanding has been found between them. The present results demonstrated that with expanding the release ratio and deviation angle, there discovered increment in the inlet sediment ratio to the intake.

Keywords:

Lateral Intake, Flow hydraulic, Sedimentation, SSIIM Model, k-ω turbulence model.

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Article Citation:
Hazhar Haddad, Edris Ahmad Ebrahimpour and Kamyar Azizi.
Numerical simulation of the inlet sedimentation rate to lateral intakes and comparison with experimental results
Journal of Research in Ecology (2017) 5(1): 464 - 472

Dates:
Received: 22 Dec 2016 **Accepted:** 18 Jan 2017 **Published:** 25 Feb 2017

Web Address:
http://ecologyresearch.info/documents/EC00226.pdf

INTRODUCTION

Erosion phenomena and sediment transport are important hydraulic processes. Water has been diverted from its original pathway since a long time ago for a variety of applications, including agriculture, urban water supply, etc. In this area of flow, fluid particles in the vicinity of the left wall of intake channel (toward the entry of the main channel) are rotational and actually this area of the lateral channel will have no effect on flow discharge rate. Complete removal of inlet sediments, is impractical and costly. Therefore, must be tried with the right policy prevent from entry of the sediments.Due to the changes in velocity distribution in the intake area, sedimentation usually occurs at the intake entrance, which leads to the reduction in intake efficiency, entry of coarse sediments into the network and the increase in administrative costs for sediment removal operations. Every step which leads to the reduction in the secondary and vortex flows at intake entrance, will lead to the reduction in sediment accumulation at intake entrance as well as reduction in the sediment entering in to the intake.

MATERIALS AND METHODS

Numerical Model and the governing equations

In this study, Navier-Stokes equations are solved by three-dimensional (Finite-Volume Method. Finite-Volume Method is based on direct discretization of the integral form of conservation laws in physical space. Flow analysis occurs at persistent mode and SIMPLE algorithm uses for velocity-pressure coupling. Several number of turbulence models exist in this numerical model. Method of discretization of momentum equation, loss and turbulence kinetic energy and Reynolds stress is two-order leading method. Also, standard method uses for discretization of pressure equation.

Considering the differential form of conservation law (equation 1), the important step in the Finite-Volume Method (FVM) is integral form of the governing equations over the control volume.

$$\frac{\partial U}{\partial t} + \vec{\nabla} \cdot \vec{F} = Q \qquad (1)$$

$$\int_{\Omega_J} \frac{\partial U}{\partial t} d\Omega + \int_{\Omega_J} \vec{\nabla} \cdot \vec{F} d\Omega = \int_{\Omega_J} Q d\Omega \qquad (2)$$

Using Gauss' divergence theorem,

$$\int_{\Omega_J} \vec{\nabla} \cdot \vec{F} d\Omega = \int_{S} \vec{F} \cdot d\vec{S} \qquad (3)$$

The integrated form of conservation law for each control volume 'Ωj' related to the point 'j' will be as follows:

$$\frac{\partial}{\partial t} \int_{\Omega_J} U d\Omega + \int_{S_J} \vec{F} \cdot d\vec{S} = \int_{\Omega_J} Q d\Omega \qquad (4)$$

The above equation is replaced by its discrete form in which the volume integral is expressed as averaged values on the cell and the surface integral as the volume total.

$$\frac{\partial}{\partial t}\left(U_J \Omega_J\right) + \sum_{faces} \vec{F} \cdot \Delta\vec{S} = Q_J \Omega_J \qquad (5)$$

where, 'U' is flow velocity, 'F' is force, 'Q' is flow discharge and 'Ωj' is control volume related to the point 'j'. Equations 6 and 7 are 3D continuity and momentum equations for turbulent flow in the incompressible fluid, respectively. Also, in different turbulence models, the turbulence kinetic energy is also defined according to the equation 8.

$$\frac{\partial \overline{U_i}}{\partial x_i} = 0 \qquad (6)$$

$$\frac{\partial \overline{U}_i}{\partial t} + (\overline{U}_j)\frac{\partial \overline{U}_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial \overline{p}}{\partial x_i} + g_{xi} + \frac{\partial}{\partial x_j}[\nu \frac{\partial \overline{U}_i}{\partial x_j} - \overline{U'_i U'_j}] \qquad (7)$$

$$k = \frac{1}{2}\overline{U_i U_i} \qquad (8)$$

where, 'ρūiūj' is Reynolds Stress, 'Ui' and 'Uj' are flow velocity in 'x and y' directions, respectively; 't' is time, 'n' is molecular viscosity, 'p' is pressure, 'k' is turbulence kinetic energy, 'ρ' is fluid density and 'gxi' is gravity acceleration in the 'xi' direction.

For bed load, an equation for balanced concentration of sediment near the bed has been developed:

$$c_{bed} = 0.015\frac{d^{0.3}}{a}\frac{\left[\frac{\tau-\tau_c}{\tau_c}\right]^{1.5}}{\left[\frac{(\rho_s-\rho_w)g}{\rho_w v^2}\right]^{0.1}} \qquad (9)$$

where, 'd' is sediment diameter, 'a' is basis level for roughness height, 'τ' is bed shear stress, 'τc' is critical shear stress, 'ρw and ρs' is water and sediment density, and 'n' is water viscosity.

In this study, the experimental data of Barkdoll *et al.* (1998) was selected for validation of the numerical simulation. In the experimental study of Barkdoll *et al.* (1998), the main channel with length of 2.74 m and the intake channel with length of 1.68 m located at 90° have been investigated. The discharge entered into the main channel (Q1) is 11 lit/s, ratio of diverted discharge (R) is 0.31, depth of flow (d) is 0.31 m. Figure 1 shows a schematic of the channel.

In this study, the main channel entrance uses the boundary condition of a given velocity with the average velocity of 0.244 m/s. Ratio of diverted discharge (R) is 0.31 according to the amount considered in the experimental model. Considering the small changes in water level, the symmetry boundary condition is applied to the water level. The rigid boundary and no-slip conditions are applied for wall. Appropriate meshing of regional which flow exists is also one of the important parameters in the model run time. Figure 2 shows the three-dimensional view of the computational domain meshing in the 90 degree intake. The total number of cells in its different areas in the x, y and z directions are 181716 cells.

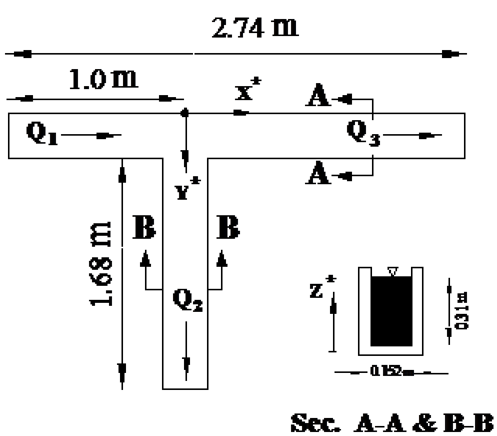


Figure 1. Geometric characteristics of laboratory flume

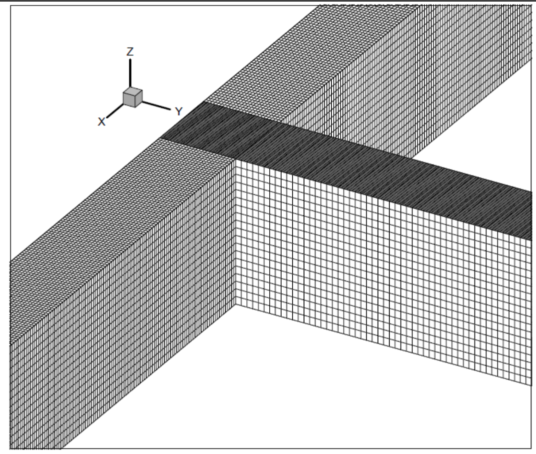


Figure 2. Three-dimensional view of the computational mesh

RESULTS AND DISCUSSION

In Figure 3, according to the experimental study, the dimensionless velocity profiles (Ux/U_0) near the water level, for different cross-sections of the main channel for entrance constant discharge of 11 lit/s, the ratio of diverted discharge (RR) and the Froude number of entrance flow Fr) are shown 0.31 and 0.13, respectively. X* and Y** are distances at x and y axes, respectively which have become dimensionless by width of intake channel. U_0 is the maximum velocity at the cross section X*=-4.65.whose value is equal to 0.28 m/s.

According to Figure 3, the velocity profile retains its expanded state before reaching the intake and when approaching the entrance, because of the suction

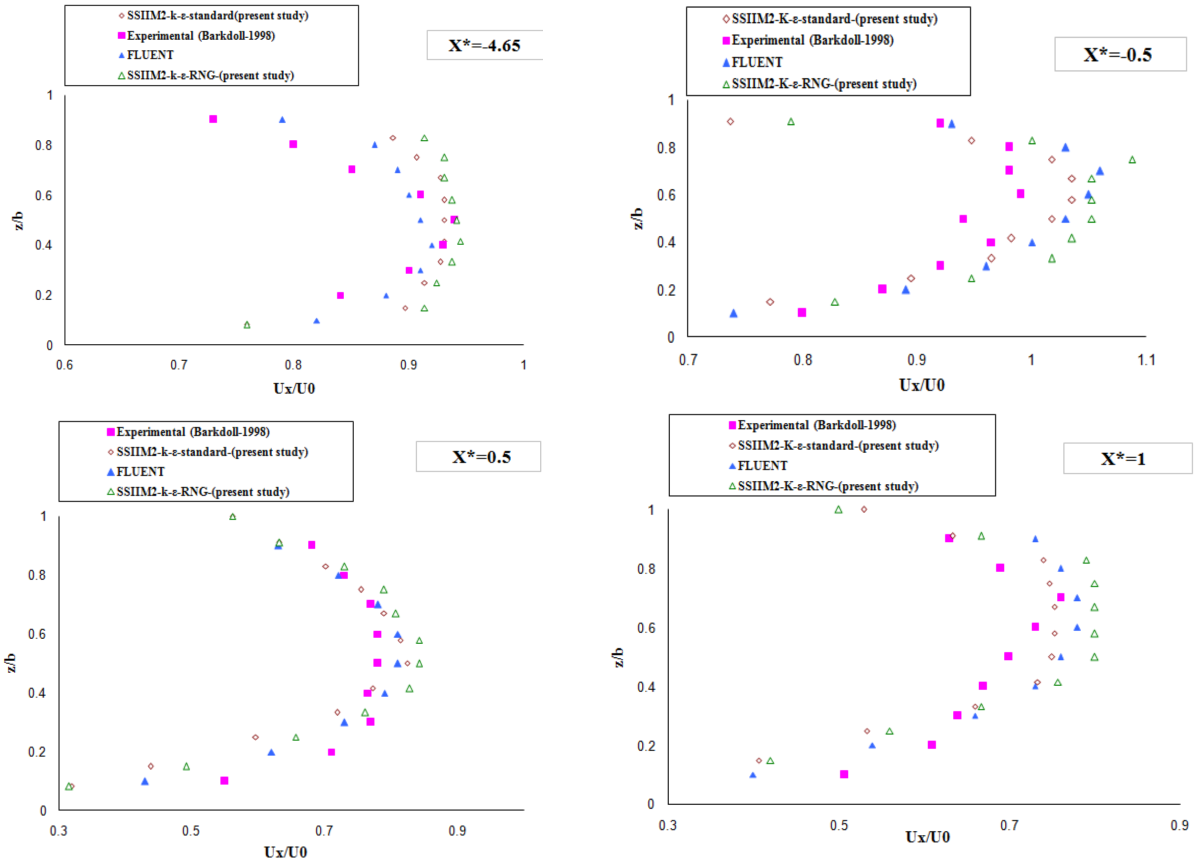


Figure 3. Simulated velocity profiles at different sections of the main channel using different turbulence

flow, the velocity profiles will be deviated towards the intake channel and the maximum velocity will be deviated toward the intake entrance (X* = -0.5). The results showed that with flow entering to the intake, velocity resultant along the intake decreases and in the downstream wall of the entrance (X* = 0.5), the maximum velocity will be distant from the inner wall of the main channel.

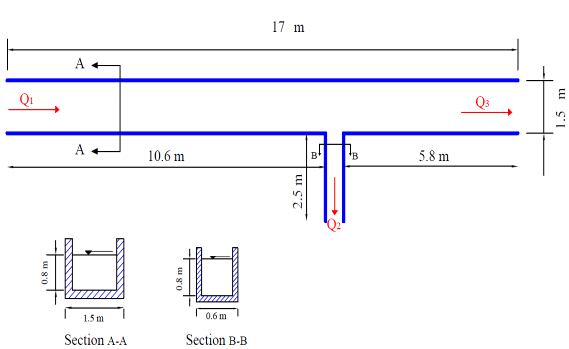


Figure 4. Schematic of the experimental flume characteristics (Abbasi, 2004)

In this part, hydraulics of the flow in an intake from a rectangular channel using SSIIM2 has been considered comparing with laboratory experiment results performed by Abbasi (2004). In their experimental set-up, the main channel was 17m long and 1.5m width and the intake was 2.5m long and 0.6m width that was at 10.6m from downstream of the main channel entrance.

The bed slope was 0.0015 and channels were 0.8m deep. Sediment particle diameter and sediments depth were 1mm and 20cm, respectively. Figure 4 shows the layout of the simulated channel.

Appropriate conditions must be specified at domain boundaries depending on the nature of the flow. In the simulation performed in the present study, velocity inlet boundary condition is specified and set to 0.065m/s and outflow boundary conditions have been used for two outlets for all of numerical modeling runs. It is also important to intention that grid independent results have

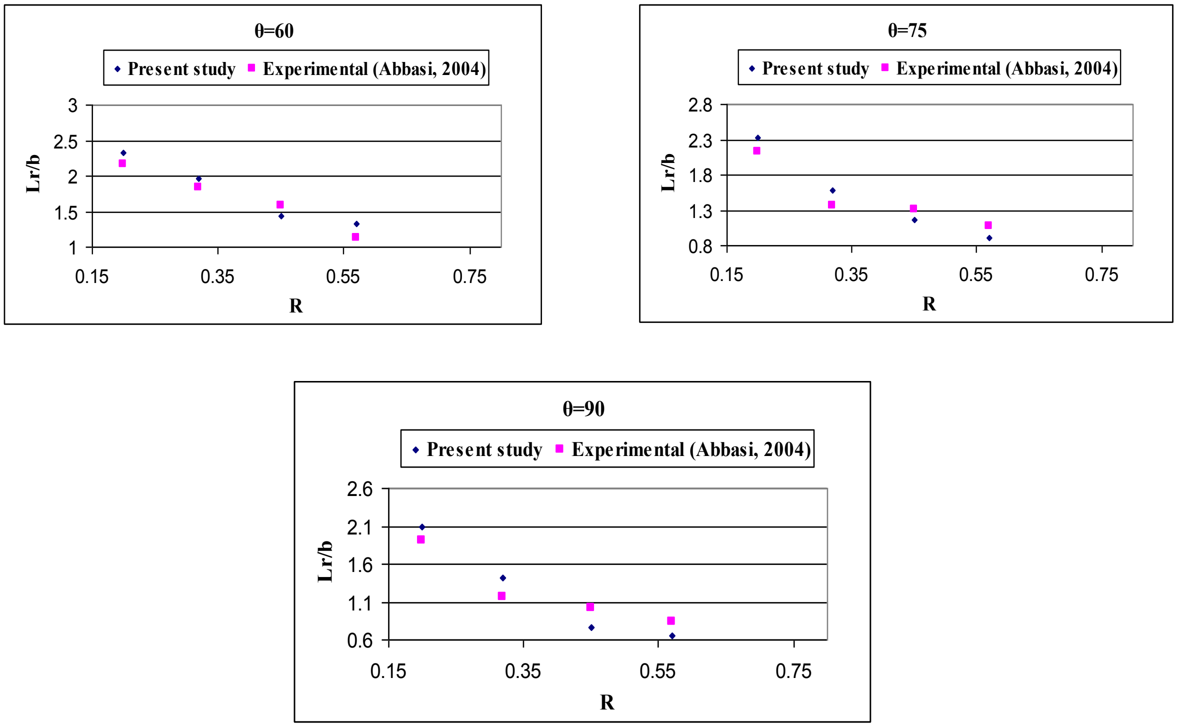


Figure 5. Created separation zones in lateral intake and comparison with experimental results

been obtained. After testing different values, cells dimensions for the main channel and the intake channel were selected 8.5×8×6.5cm and 8.5×6.5×6.5cm respectively as optimum meshing and calculations have been performed for 39382 cells.

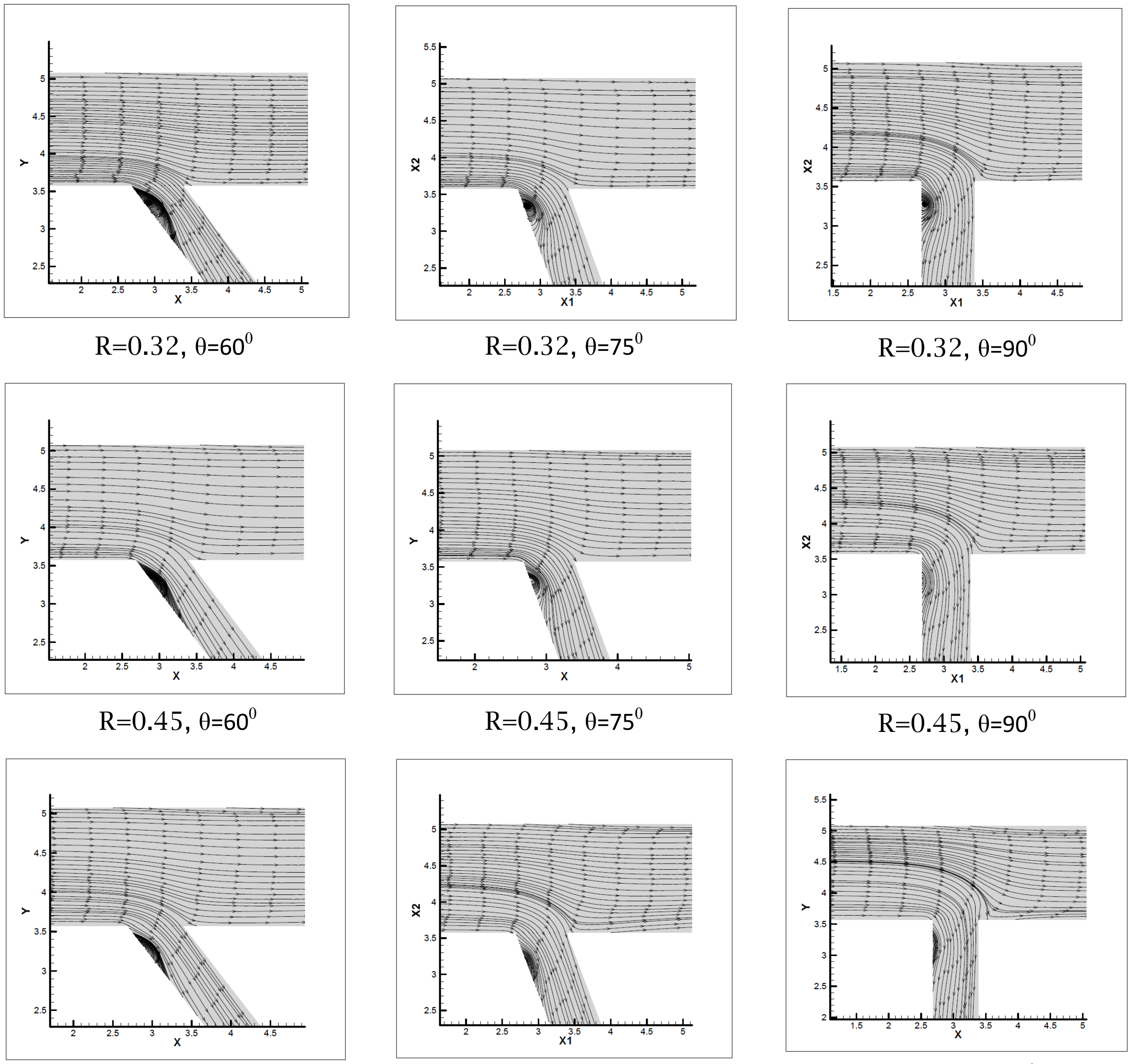
The effect of different parameters such as discharge ratio (R), deviation angle (θ) for constant Froude number in main channel (Fr) on the flow separation zones have been estimated using K-ω turbulence model. The effects of four different discharge ratios 0.2, 0.32, 0.45 and 0.57 for deviation angles of 60, 75 and 90 degree and a total discharge of 55 l/s and constant Froude number in main channel 0.4 on separation zones in Figure 5 are shown.

Consequently, for evaluation of the flow separation zone in intake, Figure 6 shows streamline at near the water surface for different discharge ratio and deviation angles.

As seen Figure 6, with increasing the discharge ratio and deviation angles, flow separation zone is decreased and increased, respectively. The effects of seven different discharge ratios 0.08, 0.096, 0.109, 0.125, 0.14, 0.205, and 0.226 for deviation angles of 450, 750 and 900 and a total discharge of 78 l/s and constant Froude number in main channel 0.4 on ratio of sediment entering to the intake in Figure 7 are shown.

Considering the obtained results at Figure 7 shows that following the experimental data and Neary and Odgaard (1993) results, when ratio of diverted discharge increases, ratio of the sediment entering to the intake will increase. An increase of the diverted discharge ratio causes entering more main channel flow into the intake an increase of the lateral velocity in front of the entrance also causes more sediments enter into the intake channel. Minimum, average and maximum errors obtained of from Fig. 7 for angle of 450 intake are 10.25%, 13.15% and 18.50% and for 75 degree intake are 11.42%, 17.04% and 21.61% and for 900 intake are 12.88%, 24.37% and 28.14% respectively. Contours of the sediment concentration in intake different sections for discharge ratio of 0.125 are showed in Figure 8.

Recently, most of the researches have focused on



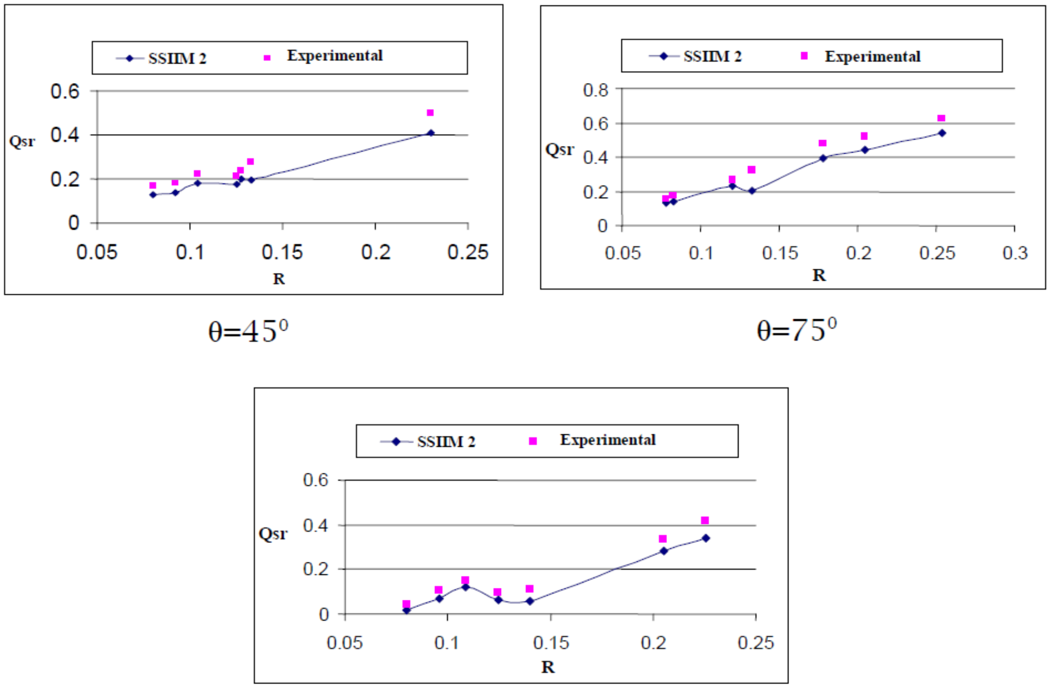
R=0.32, $\theta=60^0$ | R=0.32, $\theta=75^0$ | R=0.32, $\theta=90^0$

R=0.45, $\theta=60^0$ | R=0.45, $\theta=75^0$ | R=0.45, $\theta=90^0$

R=0.57, $\theta=60^0$ | R=0.57, $\theta=75^0$ | R=0.57, $\theta=90^0$

Figure 6. Streamlines at near the water surface for different discharge ratio and deviation angles

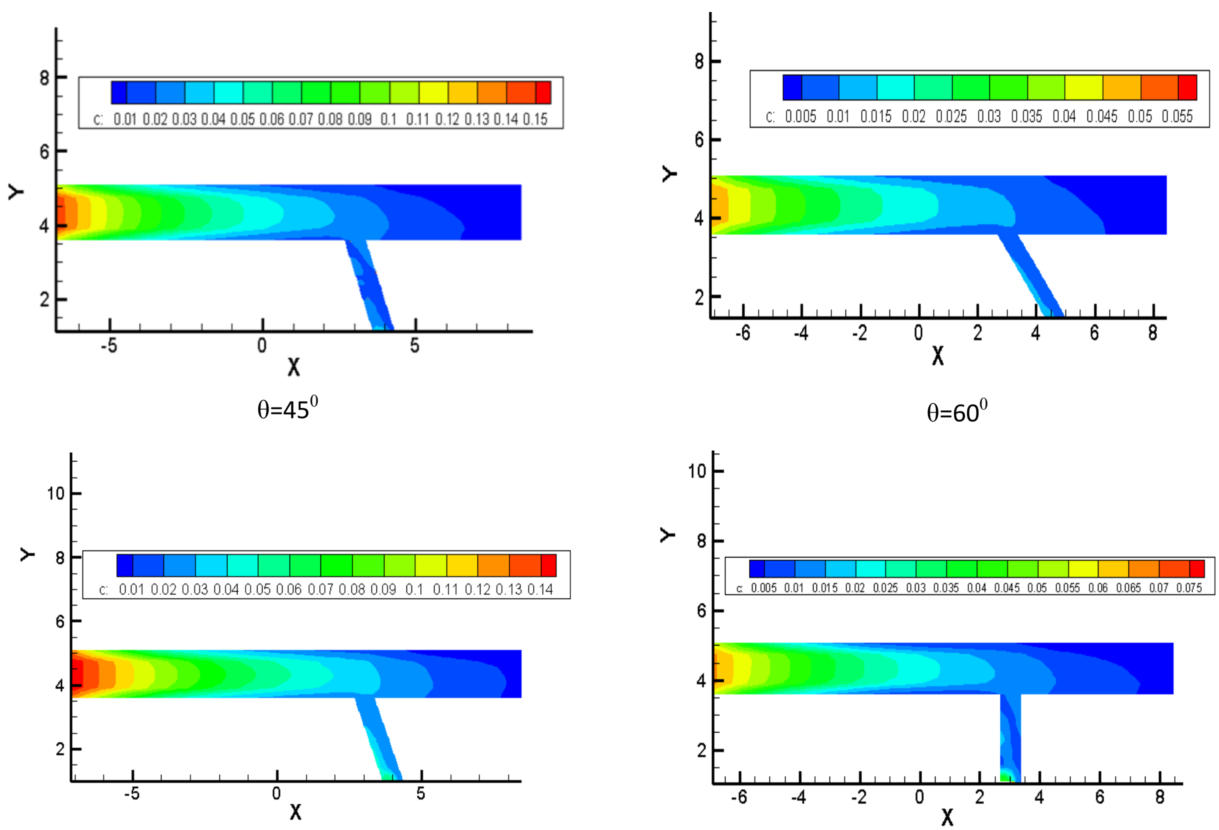
sedimentation rate of various kinds of hydraulic structures. For instance, in one of the researches, the authors have attempted to scrutinize Near shore hydrodynamics and sediment transport patterns resulted from waves and tide adjacent to a structured tidal inlet with complex bathymetry (Keshtpoor *et al.,* 2015). Their findings showed that the direction of the time-averaged alongshore sediment transport rate near the inlet and at the down drift beach is against that of the larger-scale net sediment transport along the coast (Keshtpoor *et al.,* 2015). In another study, the researchers have investigated the flow structure and sediment entry to a lateral intake. Their findings showed that the intake with a diversion angle of 1108 had the least amount of sediment entering the intake. Analysis of the streamlines in the main channel showed that the width of the bottom diverted current in the main channel decreased as the diversion angle increased (Varaki and Farhoudi, 2011). Moreover, the effect of submerged-vanes on saddle point formation and location in lateral intake is studied. The obtained results of that research indicated that use of submerged vanes with larger transverse distance is better for intake from rivers as no flow from downstream side of the intake channel returns to it (Mirzaei *et al.*, 2014). Law



θ=45⁰ θ=75⁰

θ=90⁰

Figure 7. The effects of the different discharge ratio and deviation angles on sediment entering to the intake



θ=45⁰ θ=60⁰

and Reynolds θ=75⁰ (1966) θ=90⁰

Figure 8. Contours of the sediment concentration for different deviation angles

performed an analytical and experimental study on the main channel and deviation with equal width and succeeded to present a relation for the ratio of discharges, Froude number before and after the junction, and the ratio of widths of the two channels.

Lian and Chen (1992), two-dimensionally simulated the geometry of T-junction, which was studied experimentally by Popp and Sallets in 1983, using standard K-ε model with above Reynolds numbers. The results obtained for the ratio of small discharges had proper agreement with the previous experimental measurements, but in the bigger discharges ratio, their predictions were significantly different with the measurements. Neary and Odgaard (1993) performed experimental studies on the flow hydraulics at 90° intakes. In this study, flow pattern, flow separation line, rest area, and the vortex formation area were investigated and the power of rotational flow in the vortex formation area increased with increasing the ratio of velocity in the intake channel to the main channel. Ramamurthy *et al.* (2007) performed experimental studies at 90° intake for an open channel of rectangular section and used three-dimensional precise instrumentations to measure velocity at different sections. Issa and Oliveira (1994) performed three-dimensional simulation of turbulent flow for T-shaped geometries. They solved Reynolds time-averaged Navier–Stokes equations (RANS) through K-ε-Standard model with wall functions. In their research, the equations were solved using Finite-Volume Method (FVM) with accuracy of one-order. Neary *et al.* (1999) surveyed the layer flow pattern at 90° intake by providing a three-dimensional numerical model. These researchers used Finite-Volume method for solving the equations and managed to examine flow pattern in this field and qualitatively simulate the movement of bed load sediment particles. Neary *et al.* (1999) performed a parametric study on the flow pattern in the lateral intake three-dimensionally using K-ω turbulence model. Shamloo and Pirzadeh (2008), numerically simulated flow hydraulics in the river lateral intakes using the Fluent Software. In this research, by choosing K-ε-Standard turbulence model, flow velocity profiles were evaluated three-dimensionally and a good agreement has been found between the obtained values and the experimental results. Goudarzizadeh *et al.* (2010) numerically investigated a three-dimensional examination of the flow pattern in the intake in the direct path using the finite –volume method. In this study, using k-ωturbulence model, flow velocity profiles at different sections of the main channel and intake were surveyed and compared with the experimental results. Then, for investigation of the sedimentation, effect of deviation angles of 45° to 90° and discharge ratio on the ratio of inlet sediment to intake is simulated.

CONCLUSION

The profile retains the velocity of its developed state before reaching the intake entrance and when approaching the entrance, because of the suction flow applied by the intake, the velocity profiles will be deviated towards the intake and the maximum velocity will be deviated toward the intake entrance (section $X^* = -0.5$).

-K standard turbulence model gain better results for estimation of velocity value from K-ε-RNG turbulence model, and its results estimate the positive and negative velocities in both channels with good agreement with the experimental results.

-With increasing the discharge ratio and deviation angles, flow separation zone is decreased and increased, respectively

- An increase of the diverted discharge ratio causes entering more main channel flow into the intake an increase of the lateral velocity in front of the entrance also causes more sediments enter into the intake channel.

REFERENCES

Abbasi AA. (2004). Experimental investigation on separation zone at lateral intakes entrance. Pajouhesh and Sazandegi Conference, Tehran, Iran. 38-44 p.

Barkdoll BD, Hagen BL and Odgaard AJ. (1998). Experimental comparison of dividing open channel with duct flow in T-junction. *Journal of Hydraulic Engineering,* 124(1):92-95.

Chen HB and Lian GS. (1992). The numerical computation of turbulent flow in T-junction. *Journal of Hydrodynamics,*3:50-58.

Goudarzizadeh R, Hedayat N and Mousavi Jahromi SH. (2010). Three dimensional simulation of flow pattern at the lateral intake in straight path using finite volume method. *World Academy of Science, Engineering and Technology,* 656-661.

Issa RI and Oliveira PJ. (1994). Numerical prediction of phase separation in two-phase flow through T-junctions. *Computers and Fluids,*23(2):347-372.

Keshtpoor M, Puleo JA, Shi F and Nicholas R. (2015). Simulation of nearshore hydrodynamics and sediment transport downdrift of a tidal inlet. *Journal of Waterway, Port, Coastal, and Ocean Engineering*, 141(2). http://dx.doi.org/10.1061/(ASCE)WW.1943-5460.0000273

Law SW and Reynolds AJ. (1966). Dividing flow in an ppen channel. *Journal of Hydraulic Engineering*. 92 (2):207-231.

Mirzaei SHS, Ayyoubzadeh SA and Firoozfar AR. (2014). The effect of submerged-vanes on formation location of the saddle point in lateral intake from a straight channel. *American Journal of Civil Engineering and Architecture,* 2(1): 26-33.

Neary VS and Odgaard AJ. (1993). Three dimensional flow structure at open channel diversions. *Journal of Hydraulic Engineering,*119(11):1223-1230.

Neary VS, Sotiropoulos F and Odgaard AJ. (1999). Three dimensional numerical model of Lateral Intake inflows. *Journal of Hydraulic Engineering,*125(2):126-140.

Ramamurthy AS, Junying Qu and Diep Vo. (2007). Numerical and Experimental Study of Dividing Open-Channels Flows. *Journal of Hydraulic Engineering,* 133 (10):1135-1144.

Shamloo H and Pirzadeh B. (2008). Investigation of Characteristics of Separation Zones in T-Junctions. *Journal of Wseas Transactions on Applied Mathematics,* 7(5):303-312.

Varaki ME and Farhoudi J. (2011). Study of flow structure and sediment entry to a lateral intake. *Water Management,* 164(7):347-360.