© 2012, Scienceline Publication

Journal of Civil Engineering and Urbanism

Volume 2, Issue 1: 26-34 (2012) (Received: September 24, 2011; Accepted: December 10, 2011; Published: January 25, 2012) ISSN-2252-0430

Flow Visualization in Vortex Chamber

Jafar Chapokpour[1], Javad Farhoudi[2], Ebrahim Amiri Tokaldany[3], Mahdi Majedi-Asl[4]

[1]*Post Graduate Student, Hyd. Structures, Dept. of Irrigation Eng., Faculty of Agricultural Technology and Engineering, UTCAN, University of Tehran, Iran*
[2]*Professor, Hyd. Structures, Dept. of Irrigation Eng., Faculty of Agricultural Technology and Engineering, UTCAN, University of Tehran, Iran*
[3]*Associate Professor, Hyd. Structures, Dept. of Irrigation Eng., Faculty of Agricultural Technology and Engineering, UTCAN, University of Tehran, Iran*
[4]*Member of Maragheh University, Faculty of Civil Engineering, Water Structures*

*Corresponding author's Email: jafarchabokpour@yahoo.com, jfarhoudi@ut.ac.ir, amiri@ut.ac.ir

ABSTRACT: This paper presents the results of experimental study that was accomplished in a vortex settling chamber to observe the flow structures. A polar grid of data accusation was designed to trace the velocity characteristics of the flow. An ADV three dimensional velocity measuring equipment was utilized. The experiments were conducted under four different discharges and three dimensional flow velocities were then measured. The different type secondary currents were detected in 2D manner at radial sections of vortex chamber. Additionally, it was tried to show a 3D appearance of velocity components inside the basin. It was found that flow structure of basin is highly dependent on entrance velocity. Two types of clockwise and anticlockwise vortices and some sink points combined with each other were observed in radial sections of chamber where their configurations and role were varied with flow discharge. To understand sediment trapping process in these basins, the streamlines and velocity vectors in the horizontal superimposed sections were drawn and analyzed then for motion of sediment particles the spiral settling path were observed. The 3D analyzing of sediment motion path has exhibited a different outcome from 2D analysis Such that there was not only any especial sediment motion path in the horizontal sections but also it was oriented towards up and down in its spiral circulation.

Keywords: Vortex basin, ADV velocity measuring equipment, Velocity distribution, Streamline, Sediment motion path.

ORIGINAL ARTICLE

1. INTRODUCTION

When a canal receives sediment load in excess of its sediment transport capacity and effective measures are not taken for its control, the canal gets silted up. In the case of power canals sediment particles pass through the turbines and the sharp edged silt/sand tends to damage the turbine runner blades due to abrasion, resulting in a decrease in the efficiency of the power plant. Therefore to exclude the sediment particles from the water diverted into irrigation canals or hydropower plants, sediment extractors are generally used. These extractors include the tunnel type, vortex tubes, rectangular settling basins and vortex type settling basins. The vortex settling basin (VSB), is a continuous device that apply a certain fraction of flow for flushing sediment particles [1].

Classical settling basins suffer two main disadvantages: (i) requirement of large dimensions compared with other types. (ii) Long residence time. Vortex type of sediment extractors has overcome disadvantages of conventional settling basins treating the same volume of sediment load [2].

VSB uses a vortex motion with vertical axis and centrifugal force to remove sediment from water. The secondary currents that take place in this basin move the sediment toward central orifice [3].

In this device the higher velocity flow is introduced tangentially into cylindrical basin having an orifice at center of its bottom. This gives rise to combined (Rankine type) vortex conditions with forced vortex forming near the orifice and free vortex forming the outer region toward periphery of basin. As a result, sediment concentration gradient builds up across the vortex and a diffusive flux proportional but opposite to the centrifugal flux is induced [4].

Secondary flow resulting from this causes the fluid layers near the basin floor to move toward the outlet orifice at the center. The sediment particles present in the flow move along a helical path toward central orifice, thereby obtaining a long settling length compared to the basin dimensions. Thus relatively higher velocities can be allowed in the vortex basin [4].

Under increasing discharges, when the entrance velocity increases, the central air core moves towards the central orifice and become expanded. It is also effects on decreasing of flushing discharge. It was also noted that by increasing of entrance velocity, the vortex forms better and the corresponding centrifugal force and consequently removal efficiency of the basin become greater [5].

Usually, the central flushing jet took a ring shape which become small in size, if entrance velocity increase.

To cite this paper: Chapokpour J., Farhoudi J., Amiri Tokaldany E., Majedi-Asl M. 2012. Flow Visualization in Vortex Chamber. *Journal. Civil Eng. Urban.* 2(1): 26-34.
Journal homepage: http://www.ojceu.ir/main/

It is also reported that if the employed discharge through the basin become larger than basin capacity, the disturbances in the flow of basin may occur by semi-helical displacement of air core around central orifice [5].

The sediment reaching the center can be flushed out through the orifice continuously. Relatively sediment free water is allowed to leave the basin [6]. The vortex settling basins has been investigated principally by Vokes and Jenkines (1943), Velioglu (1972), Salakhov (1975), Cecen and Bayazit (1975), Sulivan et al. (1978), Curi et al. (1979), Mashuri (1981,1986), Svarovski (1981), Ogihara and Sakagouchi (1984), Sanmogantan (1985), Esen (1989), Zhou et al. (1989, 1997), Paul et al. (1991), Ziaei (2000), Athar et al. (2002, 2003) and Gheisi (2006) [2].

Most of these investigations were focused on the trap efficiency of basin but this research focused on flow structure and formation of secondary currents in radial sections and flow direction in horizontal sections. Therefore to understand the flow structures, in horizontal and radial sections of the basin, series of flow measurement using ADV (Acoustic Doppler Velocity Meter) under clear water condition were recorded.

2. EXPERIMENTAL LAYOUT AND METHODOLOGY

The experiments were carried out in a physical model of the vortex settling basin with the characteristics shown in Table 1 and schematically depicted in Fig.1.

The tests were performed in a configuration in which the angular distance of inlet and overflow outlet was 0 degree as recommended by Paul et al. [4]. To maintain a tangential inlet flow jet in the vortex basin, a diaphragm was installed across the entrance channel at a level of 0.12m from the canal bed. Water was then supplied from a constant head tank connected through upstream stilling tank to the circulating water supply system of the laboratory where the incoming flow was regulated by means of a turning valve. Precautions were made to avoid large eddies and disturbances at the free surface of water in upstream stilling tank. The discharge from overflow weir and flushing orifice were measured by means of a pre-calibrated sharp crested rectangular weir and a V-notch respectively.

During the experiments, four different discharges were operated through the basin. The Characteristics of each experiment are mentioned in Table 2.

In every discharge, the 3D velocity components, contained tangential, radial and vertical velocities were measured using Aquatics Doppler velocity meter (ADV). The velocities were measured in eight radial sections at intervals of 45° from the origin, as shown in Fig. 2.

At each radial section 56 points were selected in a grid of velocity measurement, as demonstrated in Fig. 2, resulting in a total of 448 measuring points inside the chamber. After collection of velocity data and analyzing of them the 2D and 3D streamlines in the radial and horizontal sections were drawn and then interpreted.

Table 1. Characteristics of settling basin

Height of chamber H(m)	**Diameter of central orifice d_o(m)**	**Type of overflow weir L_1 (m)**	**Diameter of chamber d (m)**	**Basin depth at periphery h_2 (m)**	**Width of inlet channel B(m)**	**Length of inlet channel (m)**	**Slope of inlet channel S %**
0.7	0.075	circular overflow weir with crest length of 0.8	1.5	0.06	0.3	6	0.045

Table 2. Characteristics of experiments

Test no.	**Total flow (l/s)**	**Entrance velocity (m/s)**	**Discharge of Side wall weir (l/s)**	**Discharge of flushing orifice (l/s)**	**Flushing percentage (%)**
1	31.53	0.37	29.53	2	6.3
2	21.70	0.25	19.57	2.13	9.84
3	37.63	0.44	35.73	1.9	5.03
4	16.02	0.19	13.38	2.64	16.47

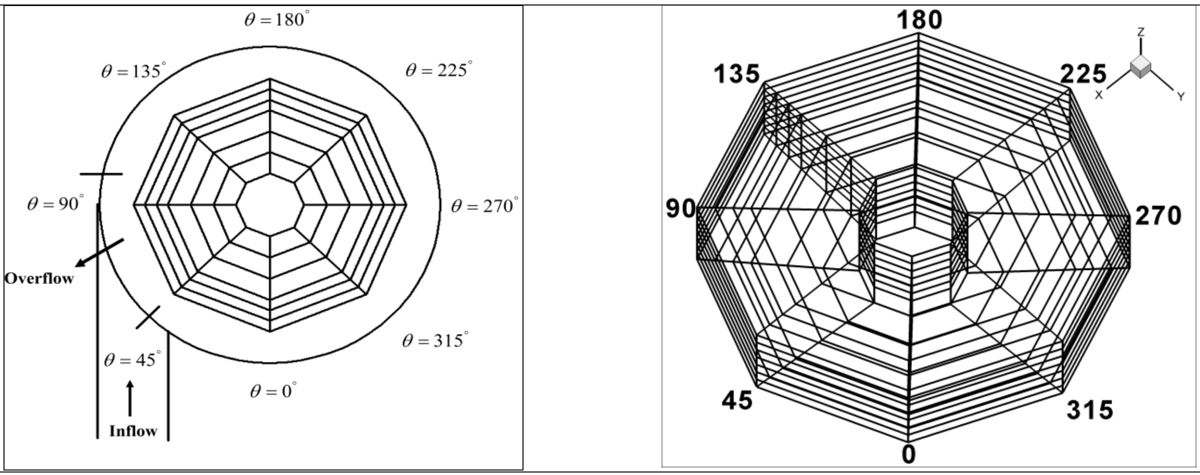
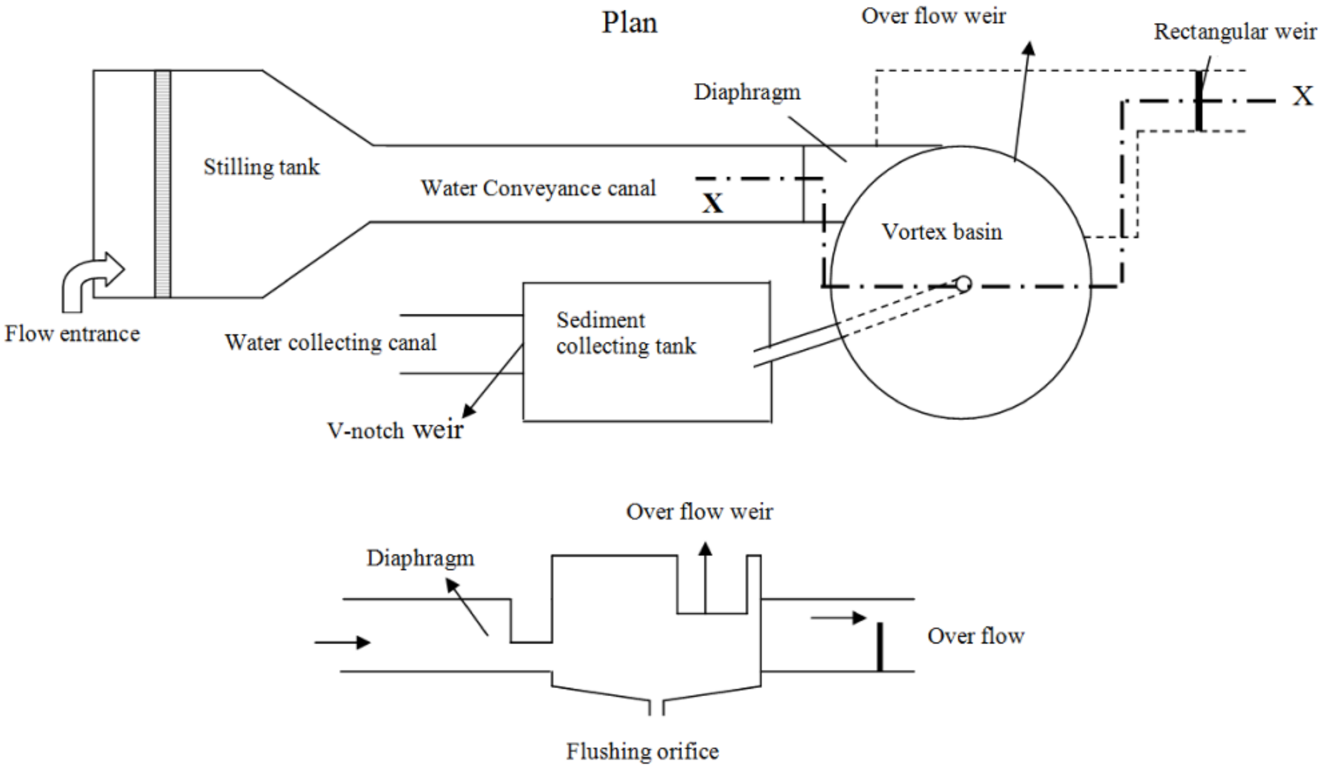
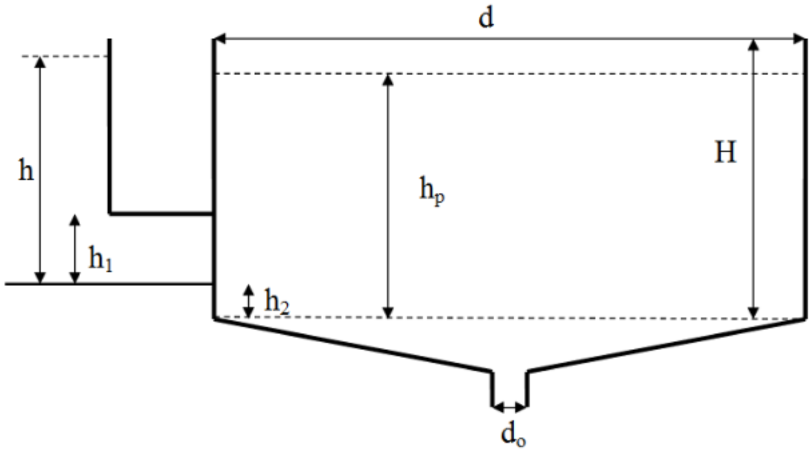


Figure 1. Grid of data collection for velocity measurement with location of entrance and overflow weir



Section X-X



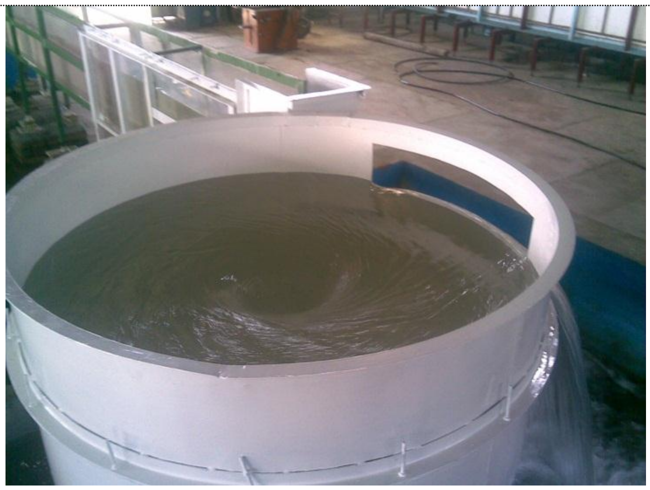


Figure 2. Schematic layout and parameters of vortex settling basin which used in the research

3. RESULTS AND DISCUSSION

3.1. Radial secondary currents

Secondary currents were generated in the vortex settling basin as a consequences of the effects raised from (i) entering water jet, (ii) over fall water jet from the curved weir crest and (iii) the bed slope of the basin towards the central orifice [4]. To realize the characteristics of secondary currents in radial sections and its influences on removal efficiency in these type sediment extractors, the velocity measurements in 2D radial sections were analyzed and streamlines depicted in Figs. 3, 4.

In this part the interpretation of radial secondary currents are outlined in the conditions of employing 31.53 (L/s) and 37.63 (L/s) with entrance velocities of 0.37 (m/s) and 0.44 (m/s) respectively to the basin.

As is illustrated in Fig. 3 for the case of 31.53 (L/s) the followings outline could be mentioned:

- At the radial section of 0°, the dominant vortex is in clockwise direction mood and located between radial distances of 0 to 50cm from the center of basin. This vortex, with a circulation tendency towards the central air core and flushing pipe, had a great influence on the sediment movement near the bed floor. On the other hands, in the regions near to sidewall a weak tendency for anticlockwise (vortex) was observed.
- In the radial section of 45°, clockwise vortex was disappeared but a weak tendency for generating of anticlockwise vortex could be found.
- In the radial section of 90°, anticlockwise vortex is generated. In this section the streamlines followed by the anticlockwise vortex with its direction from center to the sidewall. Consequently, the sediment particles will move from the centre of basin towards the sidewall depositing denser sediment layer adjacent to the wall.
- In the radial section of 135°, the powerful center of anticlockwise vortex is located at the lower depths having a dominant propagation of currents towards the central air core.
- In the radial section of the 180°, the secondary currents generally were extended towards the central air core showing the circulation of weak anticlockwise vortex and a sink point near the basin bed.
- At the radial section of 225°, sudden orientation of currents in the direction of water surface was noted where a circulating anticlockwise vortex core existed between radial distances of 45 to 55cm.
- At the radial section of 270°, it was found that the anticlockwise vortex diminished and currents were dominantly extended towards the central air core.
- At the radial section of 315°, the generation of a sink-vortex was observed, having clockwise circulation absorbing most of the streamlines with a positive role in trapping of sediments particles.

As is illustrated in Fig. 4 for the case of 37.63 (L/s) the followings outlines could be mentioned:

- At the radial section of 0°, the two types of clockwise and anticlockwise vortices were found. The clockwise vortex is located near to central air core and has a great role on the sediment trapping. And anticlockwise vortex is located far from air core and near to the basin wall having negative role on sediment trapping by transporting the sediment particles to the up side weir flow and the complete generation of anticlockwise vortex is different with previous discharge.
- In the radial section of 45°, the both of clockwise and anticlockwise vortices were disappeared. The flow tendency of the section is towards central air core. The flow pattern in this section is completely same as previous discharge.
- In the radial section of 90°, anticlockwise vortex is generating. In this section the streamlines followed by the anticlockwise vortex with its direction from center to the sidewall. Consequently, the sediment particles were moved from the centre of basin towards the sidewall depositing denser sediment layer adjacent to the wall. The flow pattern in this section is totally same as previous discharge.
- In the radial section of 135°, the powerful center of anticlockwise vortex is located at the lower depths having a dominant propagation of currents towards the central air core.
- In the radial section of the 180°, the powerful anticlockwise circulation of 135° was weakened but the total propagation of flow streamlines is towards central air core. Showing difference with previous entrance discharge.
- At the radial section of 225°, the sudden propagation of currents in the direction of water surface was noted where a circulating of weak anticlockwise vortex core existed between radial distance of 45 to 55cm. same as previous discharge.
- At the radial section of 270°, it was found that the anticlockwise vortex diminished and currents were dominantly extended towards the central air core but the overall tendency for generation of another clockwise vortex is observed.
- At the radial section of 315°, the generation of a sink-vortex was observed, having clockwise circulation absorbing most of the streamlines with a positive role in trapping of sediments particles. But in this discharge the center of sink-vortex is lower height than previous discharge.

By decreasing of entrance flow discharge to the 21.7 (L/s) and 16.02 (L/s), the types of generated streamline were the same with previous discharges but the position of Exposure was different. That is because of different magnitude and directions of vertical and radial velocities in the radial sections of basin. The effect of these currents in directing of sediment particles to flushing orifice is important. Actually existence of central oriented radial velocity beside of tangential velocity in these type basins allows to sediment particles to move in the longer path than basin dimensions. That is the most important characteristics of vortex settling basins. In the previous research that was accomplished by the authors, it was found that increasing of entrance discharge would increase the trapping efficiency of basin.

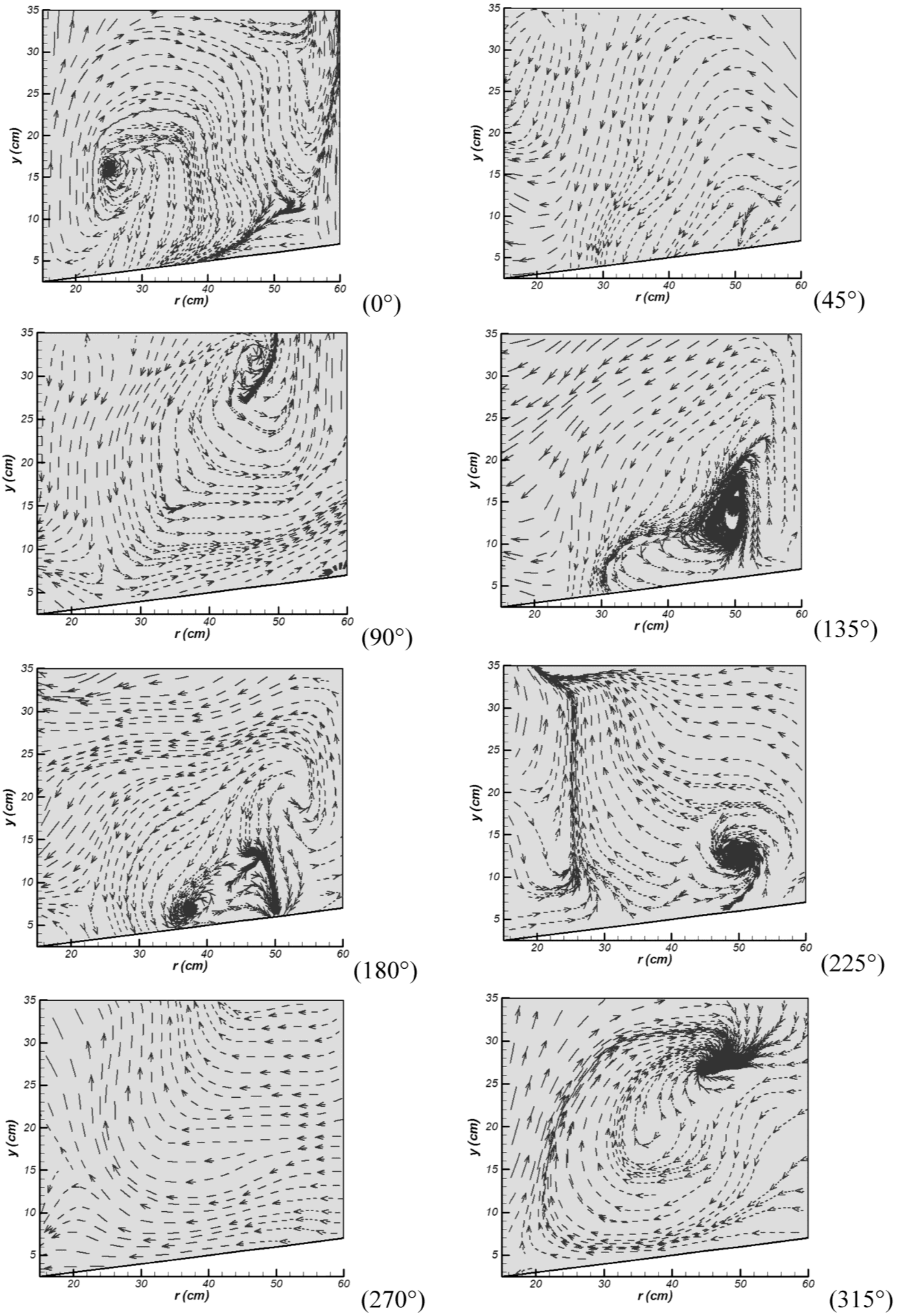
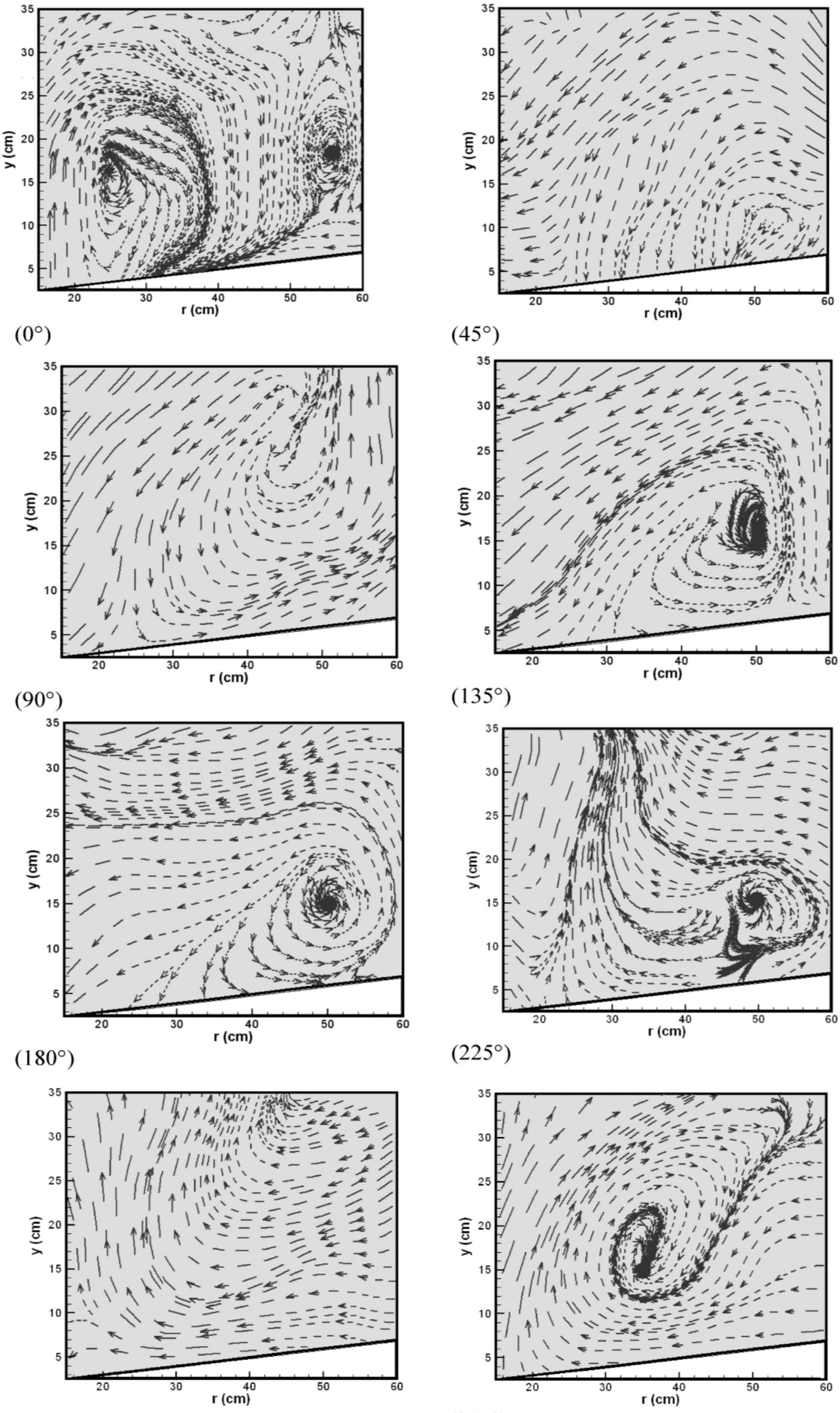


Figure 3. Flow streamlines at different radial sections whit entrance discharge of 31.53 L/s

To cite this paper: Chapokpour J., Farhoudi J., Amiri Tokaldany E., Majedi-Asl M. 2012. Flow Visualization in Vortex Chamber. *Journal. Civil Eng. Urban.* 2(1): 26-34.
Journal homepage: http://www.ojceu.ir/main/



(0°) (45°)

(90°) (135°)

(180°) (225°)

(270°) (315°)

Figure 4. Flow streamlines at different radial sections whit entrance discharge of 37.63 L/s

3.2. Vertical velocity

As is illustrated in Fig. 5 The range of magnitude of vertical velocity with entrance discharge of 21.7 (L/s) was about (-12 to 11) cm/s dependent on position of point inside of the chamber. The zones with largest positive magnitudes are around central air core and the zones with minimum negative magnitudes are positioned near the chamber wall around radial sections of 225° to 315°**.** Generally vertical velocity in main flow body is in the range of (-3 to +3) cm/s. because of existence of overflow weir a the angles of 45° to 135° the negative magnitudes of vertical velocity in mentioned sections are negligible. From distributions trend of vertical velocity in chamber it could be predicted that if a streamline move along its helical path towards central air core, a deflection would be occurred around air core because of upward vertical velocities in vicinity of air core.

This phenomenon has a good corresponding with drawn streamline path from basin entrance to central exit (Fig. 8). As is mentioned in the previous section, the vertical velocity has a great role in detection of secondary currents in radial sections which also play a powerful role in trapping actions of basin. It was also evident that at different employed discharges to the basin, the different magnitudes of vertical velocity would be occurred but the general trend was same.

3.3. X direction and Y direction velocities

Two other velocity components (V_x, V_y) are vector summation of tangential and radial velocities. They have both positive and negative magnitudes because of circulating nature of flow inside of basin. The resultant of mentioned velocities is in manner that a helical path through the X-Y plane could be observed. Range of magnitudes for these velocities is about -70 to 90 (cm/s) but these range is just in this discharge. It is evident that in the other discharges, different magnitudes were observed but the general trend is same (Figs. 6, 7).

By neglecting positive or negative signs, by motion from air core towards basin wall, decrease in magnitudes of V_x, V_y from high to constant were observed. This Characteristic belongs to free vortex flow which was observed in the regions far enough from air core in these type vortex basins. As is reported by Anwar [7] and Julien [4] a forced vortex was generated in the regions of near air core. Because of Exposure of measuring ADV inside the flow which disturbs the formation of air core, the velocity measurement in mentioned forced zone was impossible. It is also noteworthy to mention that the magnitude of tangential velocity (vector summation of V_x, V_y), in the upper zones of basin are a little higher than lower zones (Figs. 6, 7). It is because of basin boundary condition like sidewall weir.

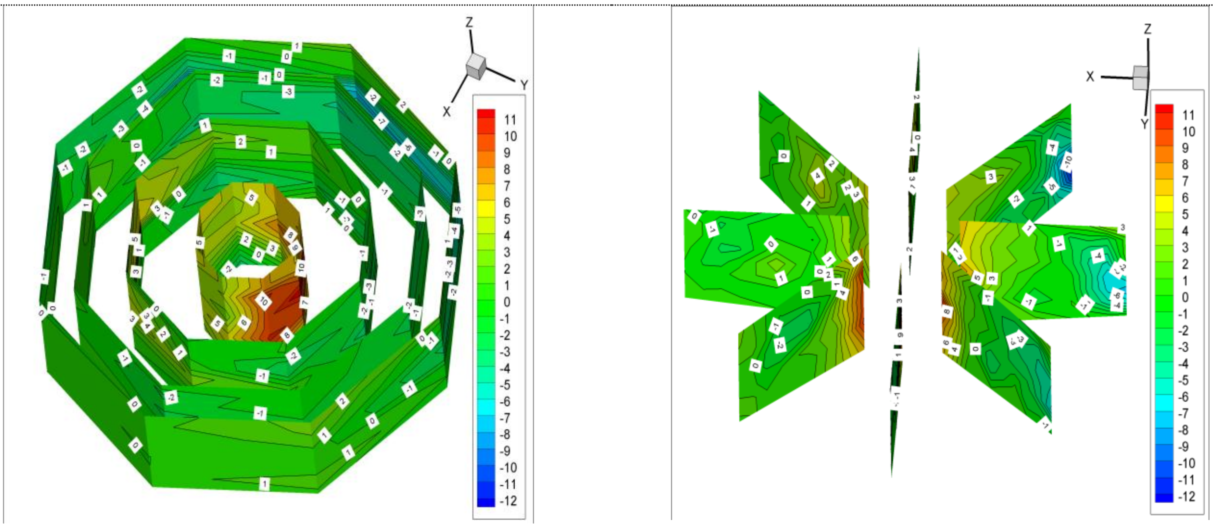


Figure 5. Contour type illustration of vertical velocity with entrance discharge of 21.70 (L/s)

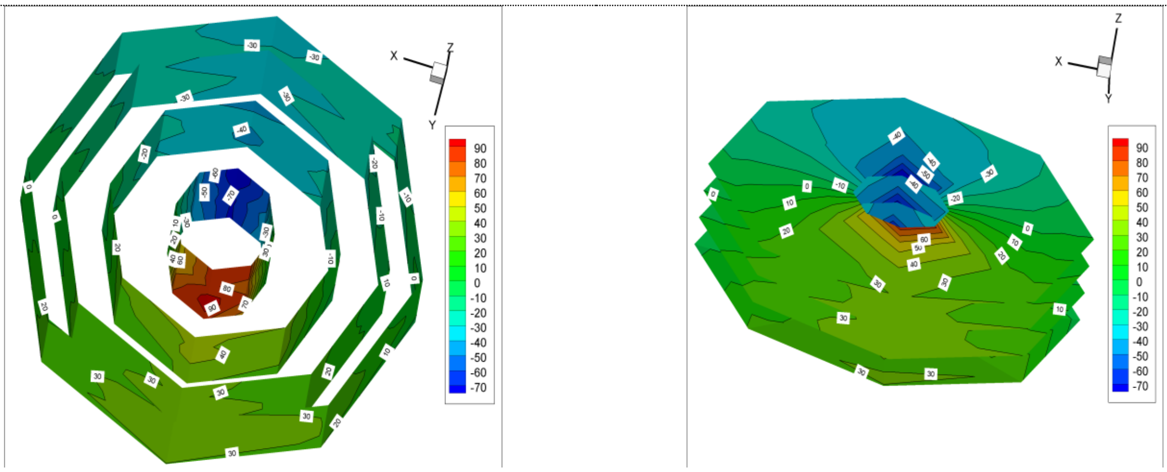


Figure 6. Contour type illustration of X direction velocity with entrance discharge of 21.70 (L/s)

To cite this paper: Chapokpour J., Farhoudi J., Amiri Tokaldany E., Majedi-Asl M. 2012. Flow Visualization in Vortex Chamber. *Journal. Civil Eng. Urban.* 2(1): 26-34.
Journal homepage: http://www.ojceu.ir/main/

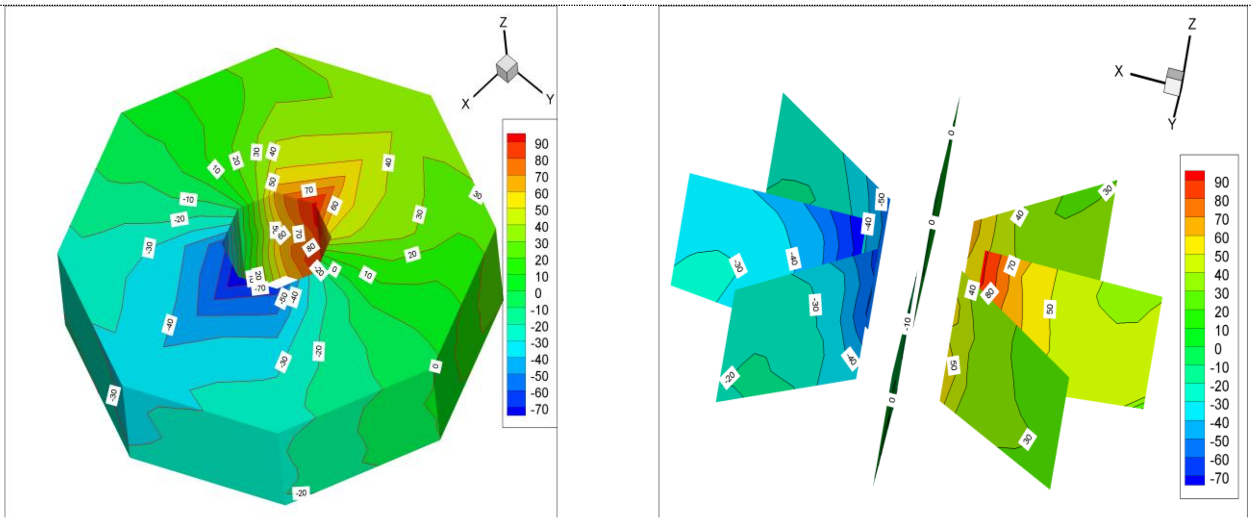


Figure 7. Contour type illustration of Y direction velocity with entrance discharge of 21.70 (L/s)

3.4. Sediment motion path

For detecting the sediment trapping path, the tangential and radial velocities in 7 horizontal sections were analyzed in 2, 3 dimensions. The first section had 11 cm distance from basin center and 7th horizontal section was in distance of 34 cm from basin center. The distance between two consecutive sections was 4 cm. With interpolation between velocity components (tangential and radial) from angle of 45° with 55cm distance from basin center and depicting of streamlines, It was found that the sediment particles have a helical circulation path inside of the vortex basin from basin entrance towards flushing exit. It was also observed that in the lower sections, direction of streamlines is towards side wall of basin and sediment particles have longer path rather than upper sections towards central orifice as sediment load (Fig. 8).

Two dimensional velocity vector analyses in the horizontal sections showed that the velocity vectors adjacent to zones of central air core is higher than those on other zones and maintain a constant magnitude near the side walls of the chamber. Despite to this observation, at the radial section of 90° from origin and zones near the entrance flow jet, velocity vectors were influenced by entrance flow jet showing an increasing magnitude by nearing to the sidewall.

The 3D analysis of velocity vectors and streamlines has exhibited a little different result Fig.8. That was because of interaction between vertical velocity and horizontal plane's vector. In fact it was observed that every streamline or sediment motion path was not only positioned in a one horizontal plane but also was directed from especial height towards upper heights in vicinity of central air core. Indeed by following the streamline from basin entrance towards central exit, firstly it was oriented to lower heights in its helical path but whatever it become near to the air core, it was affected by positive magnitudes of vertical velocity therefore oriented towards upper heights in the vicinity of air core (Fig. 8).

It is also noteworthy to mention that when the colored contaminant injected to outer face of air core, its direction towards central flushing exit are downward against previously mentioned observation.

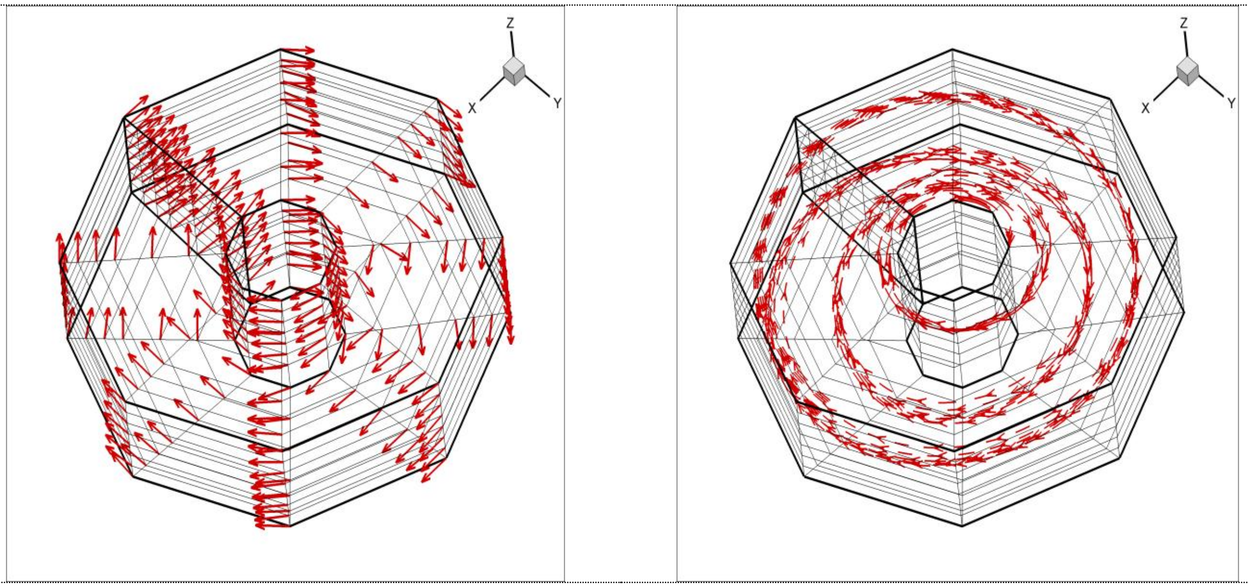


Figure 8. Velocity vectors and flow streamlines in 3D illustration with entrance discharge of 21.70 (L/s)

4. CONCLUSION

As compared by other sediment extractors, vortex settling basin is efficient device and has advantage of being self-flushing. Unlike classical settling basins the vortex settling basin needs for higher inlet velocity to maintain a higher efficiency in both hydraulically and sediment aspects. To achieve higher entrance velocity, a new geometric configuration with smaller entrance orifice from which the previous investigators pointed, was identified in this investigation.

An increase in the incoming velocity generates a powerful centrifugal forced vortex causing a better formation of central air core with smaller flushing ring diameter which results in higher hydraulic efficiencies of the basin.

The new comparison between 2, 3 dimensional streamline paths was used to observe the real sediment motion path in the basin. It was found that the effect of vertical velocity in upward and downward orienting of path is important. At the regions in vicinity of central air core vertical velocity is upward but in the regions far enough from basin center, vertical velocity is downward. It was also found that in the lower flow layers the sediment particles take a longer helical path towards flushing orifice which would result a higher concentration of sediment around flushing orifice rather than upper flow layers.

By drawing of secondary currents in radial sections of basin, it was found that different types of flow patterns were generated combined whit each other which may play a positive or negative role in sediment trapping actions of basin. By comparison between different discharges, it was also found that the types of secondary flow pattern are same but the position of each pattern are different which may play a different role in trapping actions.

Comparing the magnitude of velocity and streamline path in horizontal sections with occurrence of secondary currants in radial sections, it was revealed that the flow in the main spiral direction plays a higher role on removal efficiency of basin.

REFERENCES

1. Athar, M., Kothyari, U.C. and Garde, R.J. 2002. Sediment removal efficiency of vortex chamber type sediment extractor. J. Hyd. Engng, ASCE 128(2): 1051-1059.
2. Keshavarzi, A.R. and Gheisi, A.R. 2006. Trap efficiency of vortex settling basin for exclusion of fine suspended particles in irrigation canals. J. Irrig. Drain. Engng. 55(4): 419-434.
3. Ziaei, A.N., Javan, M. and Keshavarzi, A.L. 2001. “A new feature of vortex settling basin (VSB). In Proceedings of International Conference on Hydraulic Structures, Kerman, Iran, vol. 3, pp. 41-54.
4. Paul, T.C., Sayal, S.K., Sakhanja, V.S. and Dhillon, G.S. 1991. Vortex settling chamber design considerations”, J. Hyd. Engng, 117, No. 2, pp. 172-189.
5. Chapokpour. J. and Farhoudi, J. 2011. Sediment extraction and flow structure of vortex settling basin. WASJ. 14(5): 782-793.
6. Mashauri., D.A. 1986. Modeling of vortex settling chamber for primary clarification of water, PhD thesis, Tampere University of Technology, Tampere, Finland, 217 pp.
7. Anwar, H.O. 1969. Turbulent flow in a vortex. J. Hydr. Res., 7(1), 1-29.
8. Cecen, K. and Akmandor, N. 1973. Circular settling basins with horizontal floor. MAG Report No 183, TETAK, Ankara, Turkey.
9. Cecen, K. and Bayazit M. 1975. Some laboratory studies of sediment controlling structures calculation of load-controlling water intake structures for Mountain Rivers. Proceedings of the Ninth Congress of the ICID, Moscow, Soviet Union, pp. 107-110.
10. Salakhov, F.S. 1975. Rotational design and methods of hydraulic calculation of load-controlling water intake structures for Mountain Rivers. Proceedings of Ninth Congress of the ICID, Moscow, Soviet Union, 151-161.
11. Cecen, K. 1977. Hydraulic criteria of settling basins for water treatment, hydro-power and irrigation. Proc. 17th Congress of the Int. Assoc, of Hydr. Res., BadenBaden, West Germany, 275-294.
12. Chrysostomou, V., 1983. Vortex-type settling basin, thesis presented to the University of Southampton, at Southampton, England, in partial fulfillment of the requirements for the degree of Master of Science.
13. Rea, Q. 1984. Secondary currents within the circulation chamber sediment extractor, thesis presented to the University of Southampton, at Southampton, England, in partial fulfillment of the requirements for the degree of Master of Science.
14. Gard, R.J. and Ranga Raju, K.G. 2000. Mechanics of sediment transportation and alluvial stream problems, 3rd Edn. New Age International, New Dehli, India.

To cite this paper: Chapokpour J., Farhoudi J., Amiri Tokaldany E., Majedi-Asl M. 2012. Flow Visualization in Vortex Chamber. *Journal. Civil Eng. Urban.* 2(1): 26-34.
Journal homepage: http://www.ojceu.ir/main/