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Velocity Distribution in Vortex Settling Basins

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ABSTRACT

Present paper deals with the results of the experimental investigation regarding the velocity distribution inside the vortex settling Basins. Data are collected in the laboratory on vortex chamber type settling basins with two geometric configurations. A Programmable Electro-Magnetic Shunt (P.E.M.S.) flow meter is used to measure the tangential and radial components of velocity along vertical, tangential and radial directions at well defined nodal points inside the basins. Graphs for tangential and radial velocities are plotted. at various depths along radius of the basins at 8% water abstraction ratio. It is found that velocity distribution throughout the chamber is not uniform due to unsymmetrical positions of inlet, outlet channels and under flow outlet. In some part of the chamber it follows the law of Rankine vortex type velocity distribution.

KEY WORDS

Velocity Distribution, Vortex Chamber type settling basin, Rankine Vortex, Water Abstraction Ratio, Tangential and Radial Velocities.

1. INTRODUCTION

To trap the silt from the canals, many silt trapping devices such as conventional settling basin, tunnel type extractor, vortex tube are in common use. All these devices have their inherent advantages and disadvantages. It was found after extensive literature survey that about 20 to 25 % canal discharge is needed to extract the silt from the canal. A vortex chamber type settling basin/extractor is a device which requires only about 8 to 10 % canal discharge to extract same amount of silt with same silt gradation and silt charge. It is a fluidic device, which makes use of the vortices of the flow in a chamber or a basin for separation of sediment particles from the flow. A higher velocity flow is introduced tangentially into a cylindrical chamber/basin having an orifice/outlet at the center of its bottom. This gives rise to combined vortex conditions (Rankine vortex) with forced vortex near the orifice at the center and free vortex in the outer region towards the periphery. Sediment particles being heavier than water are forced towards the periphery of the chamber due to centrifugal force imparted by vortex flow to them. The secondary flow resulting due to combined vortex causes the fluid layers near the chamber periphery to move towards the outlet orifice at the center along the chamber bottom, as a result the sediment particles from the chamber periphery move with the flow along a helicoidal path towards the orifice, thereby obtaining a settling length which is longer than basin dimensions. Thus relative higher inflow velocities can be allowed into the chamber. The sediment reaching the center of the chamber can be flushed out through the orifice continuously. Relatively sediment free water is allowed to leave the chamber through an outlet channel/pipe taking off from the chamber at a location of relatively higher elevation.

2. BRIEF REVIEW

The flow mechanism in a vortex chamber sediment extractor is similar to the Rankine Vortex in which a forced vortex core is surrounded by an irrotational or free vortex zone (Julien, 1985 a & b). Several investigators for investigating the flow structure and similarity in vortex chambers have conducted experimental studies. Notable amongst these includes those by Anwer (1965), Cecen (1977), Daggett and Keulegan (1977), Julien (1985 a and b), Odgaard (1986), Vasistas et al. (1989) and Hite & Mih (1994), Mujib et al. (2008, 2012). A brief review presented herein indicates that most of the investigators mainly observed the tangential velocity inside the vortex chamber. A smaller number of studies are however available in which both the radial and tangential velocities were measured for study the flow pattern in the vortex chamber. Hence in present paper the emphasis is given to collect more and more data on velocity distribution for radial as well as tangential directions.

The flow mechanism inside the vortex settling basin is very complicated due to the effect of the inflow, underflow and overflow conditions. Since the variation of sediment concentration within the chamber of a vortex extractor is greatly affected by variations in the velocity components in vertical, radial and tangential directions of the basin, a complete knowledge about the flow field inside the basin is therefore necessary in modeling of the vortex chamber type settling basins for their effectiveness in removing the sediment from the flow. This paper is intended to present the flow field structure in the vortex basins at 8% water abstraction ratio by laboratory measurements.

3. THEORETICAL TREATMENT

It is evident from the extensive literature review that the expressions for velocity distribution in the vortex chambers have been derived by assuming axi-symmetric flows and by approximating the turbulence by mixing length model, it is not easy to model turbulence even in simplest of the flow condition whereas the vortex flow that occurs in the vortex basin is quite complex. Keeping these points in mind it is decided to study the velocity distributions in the vortex basins by making use of experimental observations.

Following functional relationships are assumed to hold good for the radial and tangential velocity components.

$$vt = \mathrm{f}_2\left(V_i,\ R,\ r,\ ^{-},\ Q_u,\ Q_i\right) \qquad \text{(1a}$$

$$v_r = \mathrm{f}_1\left(V_i,\ R,\ r,\ ^{-},\ Q_u,\ Q_i\right) \qquad \text{(1b)}$$

Here v_r and vt are the radial and tangential velocities, R is the radius of the chamber, r is the radial spacing, Q_u is the underflow discharge and Q_i is discharge in the inlet channel. Carrying dimensional analysis for above variables using Bakingham's Pi-theorem method, following equations in terms of non-dimensional variables are obtained as follows.

$$v_r/V_i = ¤_1\left(Q_u/Q_i,^{-},r/R\right) \qquad \text{(2a)}$$

$$vt/V_i = ¤_2\left(Q_u/Q_i,^{-},r/R\right) \qquad \text{(2b)}$$

4. EXPERIMENTAL PROGRAMME

The experimental work being reported herein was part of major programme on study of vortex chamber type sediment extractor. Details on these are available in Athar (2001). These experiments were conducted in the hydraulics laboratory of the University of Roorkee, India (Presently I. I. T. Roorkee).

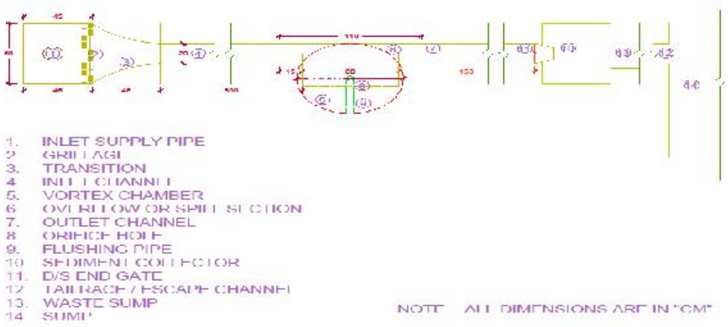


Fig.1 Plan of Experimental Set-up

Circular cylinder vortex basins having internal diameter equal to 1.0 m with geometric configuration as shown in Fig.1 is used. The basins are made of 6 mm thick perspex sheet. The bottom is made of painted steel and it is given to a slope of 1:10 towards the centre to facilitate the sediment movement towards the outlet orifice at the centre. The internal diameter and over all height of the chamber are kept as 1m and 0.45 m respectively. These dimensions are chosen on the basis of the space and discharge available in the laboratory and also considering the investigations of Sullivan (1972), Cecen & Bayazit (1975), Salakhov (1975), Mashauri (1986) and Paul (1991). Circular railing is provided along the top of the vortex chamber for supporting the equipment used in the measurement. A sharp edged orifice with internal diameter of 0.10 m is provided at the centre of the chamber. The orifice is further connected to an underflow outlet pipe with diameter equal 0.10 m for flushing out the sediment collected at the centre of the vortex chamber. A gate valve is provided at the outlet of this pipe to regulate the flow through it.

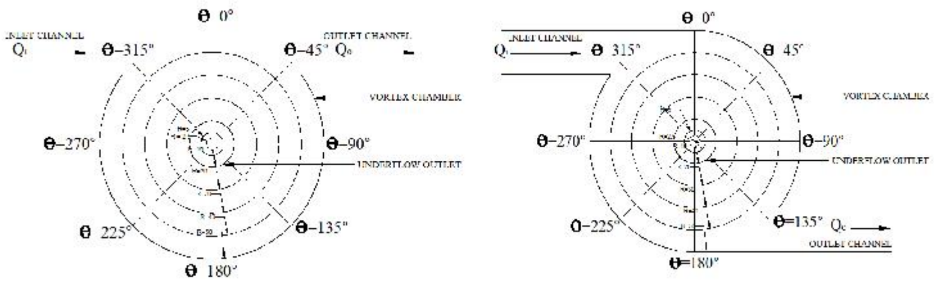
The inlet channel used in basins is 6.5 m long, 0.20 m wide and 0.25 m deep and has adjustable slope. The inlet channel bed and walls are made-up of painted steel. The outflow outlet channels provided in the basin are 2.5 m long, 0.20 m wide and 0.25 m deep and has adjustable slope. Circular steel pipes are used as the railing in the inlet and the overflow outlet channels and they are made parallel to the channel beds by adjusting the railing screws. The straight inlet channel joined the vortex chamber tangentially at its one side. The straight outlet channel was taken off tangentially to the chamber but from the point that was diametrically opposite to the junction of the inlet channel .

4.1. Electromagnetic Liquid Velocity Meter (PEMS)

Fig.2 PEMS Meter

A programmable Electro-Magnetic Liquid Velocity Meter (Fig.2)manufactured in the Delft Hydraulics Laboratory is used for measuring the velocity components of the flow in the vortex chamber. This instrument consists of a disc-type probe, which is placed, vertically in the flow. It scene the motion of the fluid by electric pulses.

4.2. Measurements by P.E.M.S.



Geometric Model type-I Geometric Model type-II

Fig.3 Secterisation of Vortex Basins

The both vortex basins are first divided into eight sectors i.e. angular segments. These all eight sectors are further subdivided into five annular segments (Fig.3)) thus forming about 40 nodal points in a horizontal planes. Further 240 nodal points were assumed for taking observations for velocities assuming 5 z values (depths measured from bottom). The P.E.M.S. probe is fixed with a vertical gauge and the whole assembly is mounted on the horizontal circular railing fixed over the basins. The P.E.M.S. probe could be moved horizontally as well as vertically up and down. For measuring the velocity components, the P.E.M.S. moved to five different levels along the nodal points thus created.

5. ANALYSIS OF DATA

5.1. Velocity Distributions

Data for the velocity components along radial and tangential directions at various nodal points within the vortexbasins were measured simultaneously using 2D-Electromagnetic liquid velocity meter. Non-dimensional velocity components defined as vt/V_i) and defined as v_r/V_i) for different z values were plotted against non-dimensional radial spacing r/R along each of the chamber diameter marked in Fig.2(a) and (b) for all the runs. Many graphs for tangential and radial velocity distributions were obtained along various radius of the chamber.

5.1.1 Variations of Tangential and Radial Velocities along Vertical direction

Figures 4 and 5 show the variations of tangential and radial velocities along vertical direction at few radial locations for the geometric models of the vortex basins. Here the results and graphs are shown for four θ values ie. at 0°, 90°, 180° and 270°.It is clear that these velocities are varying in vertical direction but effect is less pronounced. These graphs are almost similar in both the models of the basins.

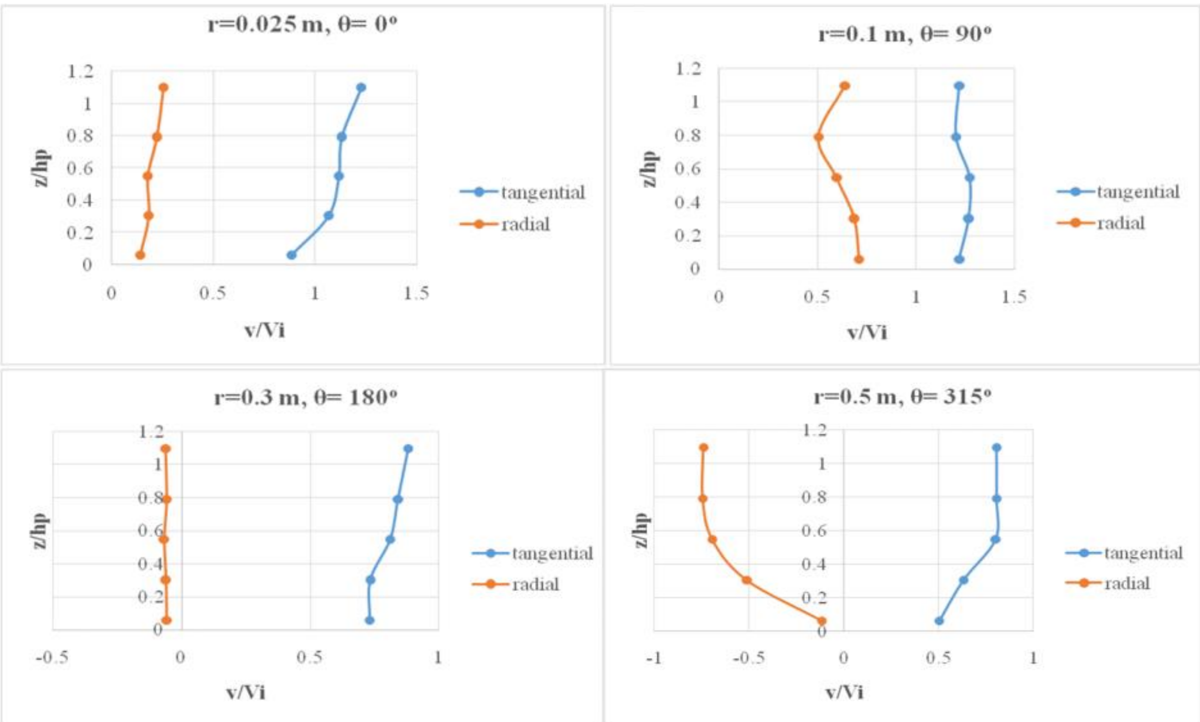


Fig.4 Variation of Tangential and Radial Velocities along Vertical Direction for Model - I

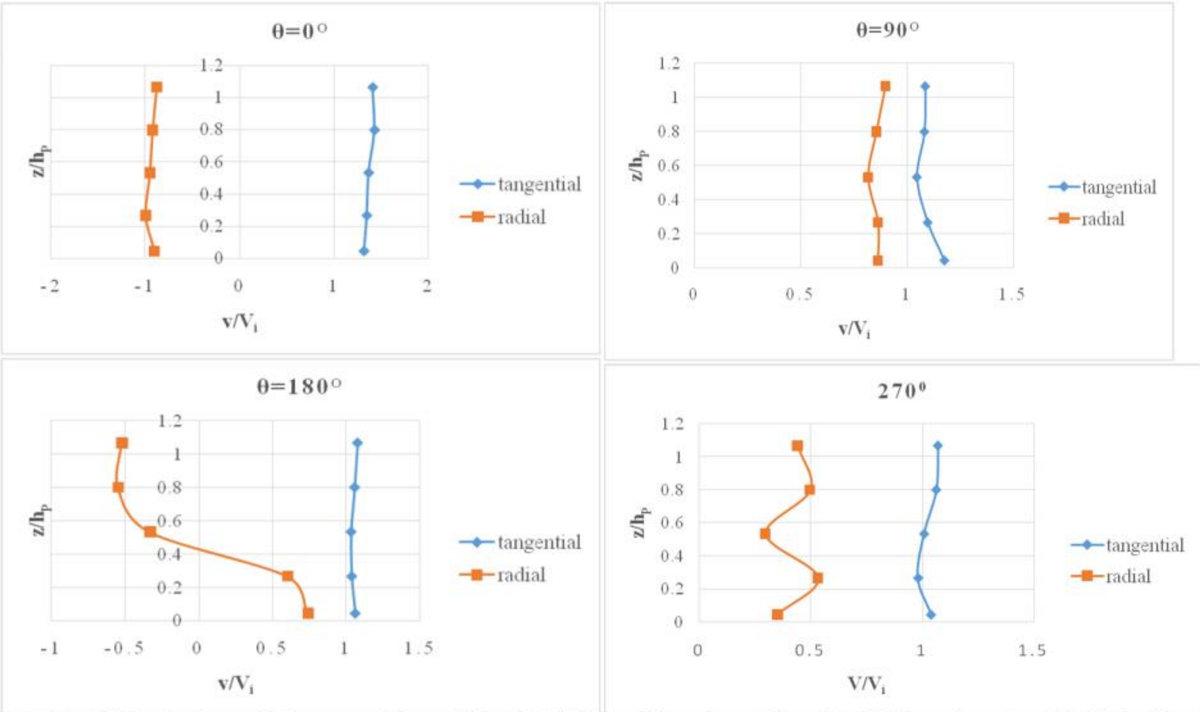


Fig. 5 Variation of Tangential and Radial Velocities along Vertical Direction for Model – I

5.1.2 Variation of Tangential Velocity along Radial direction

For both the geometric models of the basin, tangential velocity were plotted along radial direction as shown in Figs 6 and 7. It is clear that in both the models, the variations along radial direction is similar almost at all θ values. At $\theta = 90^o$, 180^o and 270^o, Rankine type vortex is formed where very near to centre there is forced vortex and after that velocity profile follows free vortex law ie. $v \propto 1/r$.

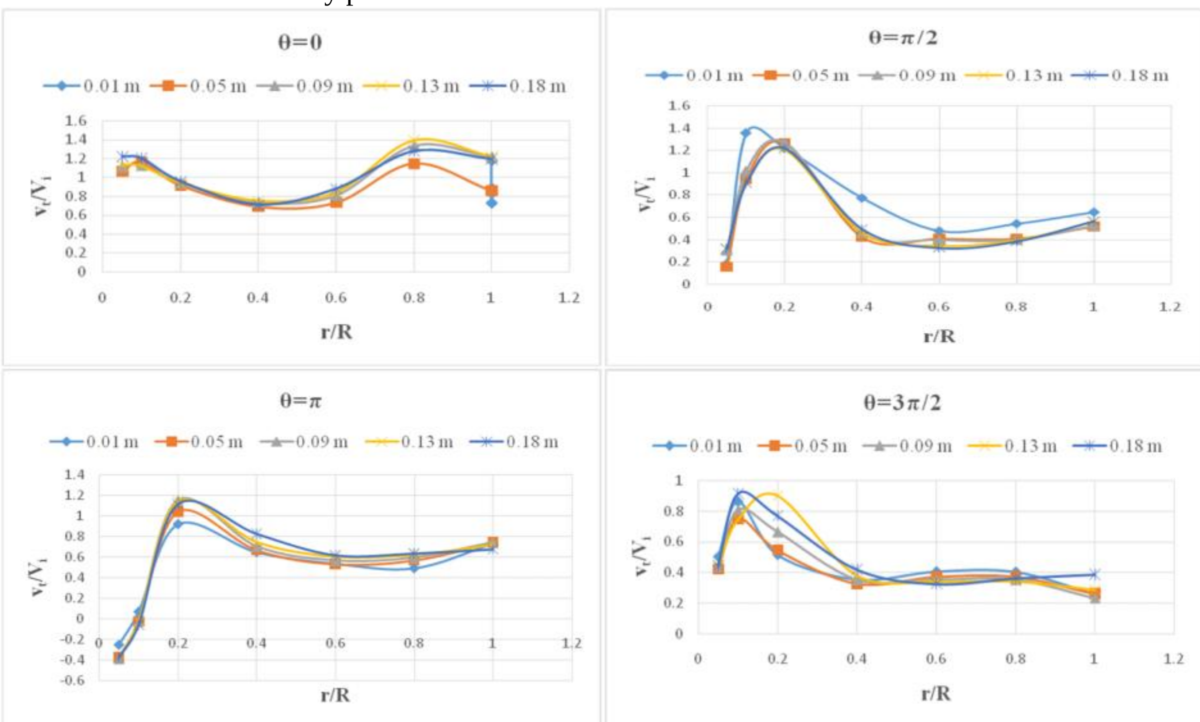


Fig.6 Variation of Tangential Velocity along Radial Direction for Model - I

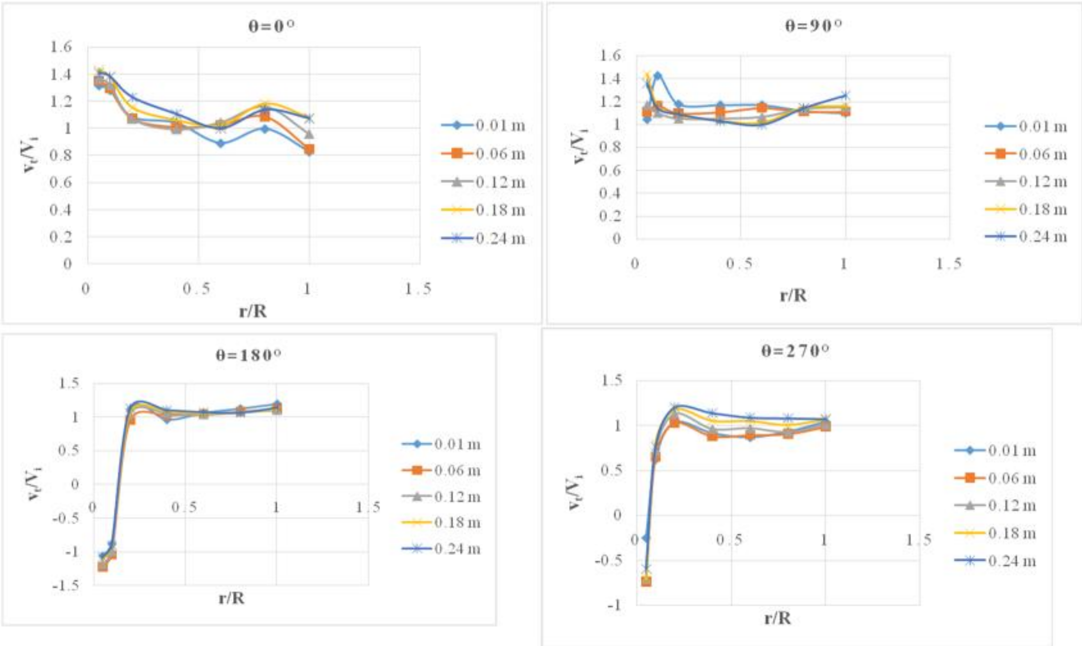


Fig.7 Variation of Tangential Velocity along Radial Direction for Model - II

5.1.3 Variation of Radial Velocity along Radial direction

Same data have also been plotted to observe the variation of radial velocity along radial direction of the models of the vortex basins. Theses plots were only plotted for θ values= 0^o, 90^o, 180^o and 270^o likewise tangential velocity distribution. Radial velocity graphs are not uniform and following any well defined law except for one or two θ values. However, it is find the negative values with larger magnitudes were obtained at θ = 180^o and 270^o.This may be attributed that when flow in the basins move from 90o onwards, the flow entres into the underflow outlet with high speed showing negative velocity values. This phenomenon will be quite helpful in extracting the silt moving in the basin with the flow.

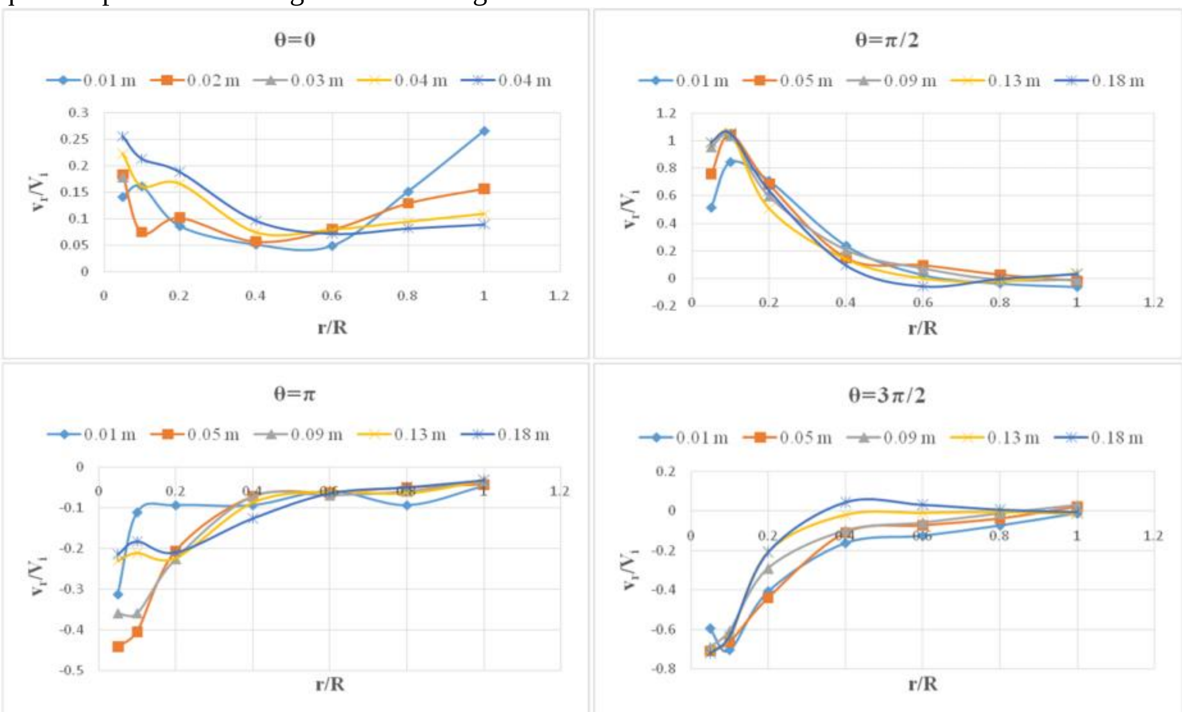


Fig.8 Variation of Radial Velocity along Radial Direction for Model - I

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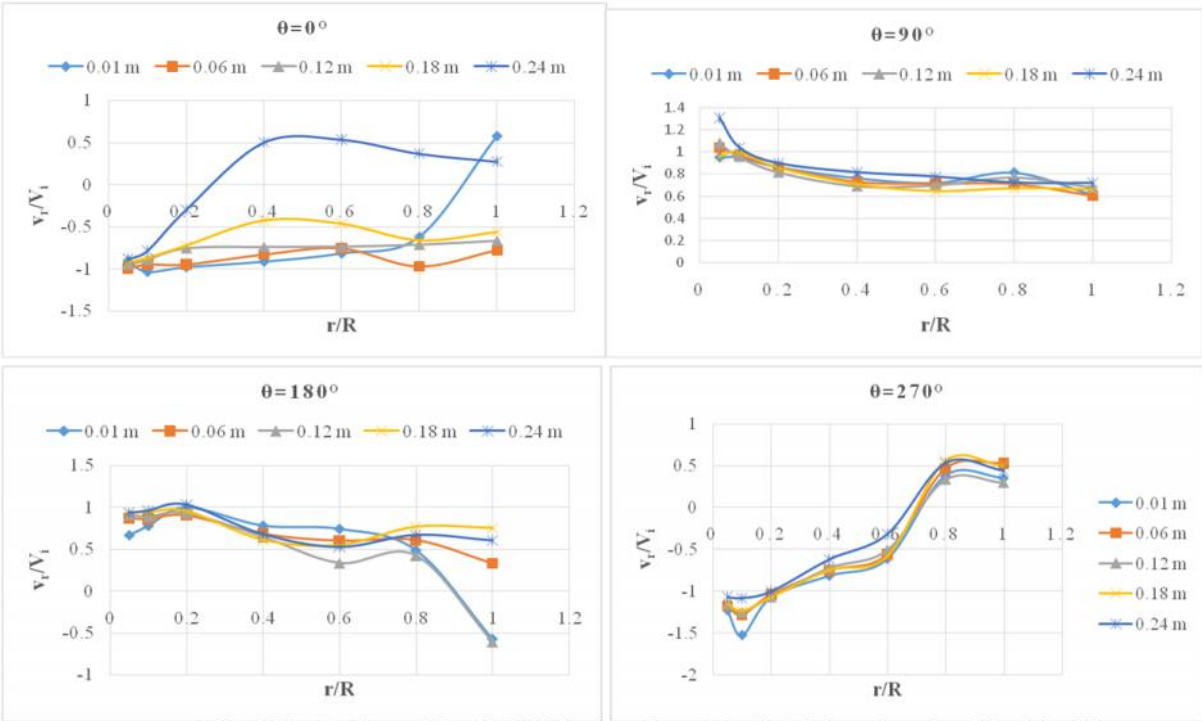

Fig.9 Variation of Radial Velocity along Radial Direction for Model - II

6. CONCLUSIONS

Following conclusions are made**:**

1. Within the vortex chamber, the velocities in tangential and radial directions are found to vary along vertical direction but the effect is less pronounced.
2. Flow patterns are found to be different in the different segments of the vortex chamber. Segments of vortex chamber having flow pattern similar to that Rankine vortex extended only up to half diameter length of the vortex chambers.
3. Likewise tangential velocities, the radial velocities seem to follow Rankine vortex law in some segment of the chamber.
4. The higher and negative values of radial velocity show that the radial velocity will be more significant in extracting the silt from the bed of the basin.
5. The results of both geometric models are almost similar. But there is slight effect of outlet (overflow) channels on velocity distributions.

7. SYMBOLS

R	=	Radius of the vortex chamber
r	=	Radial spacing
r/R	=	Dimensionless radial spacing
Q_i	=	Discharge in the inlet channel
Q_u	=	Discharge in the overflow outlet
Q_u/Q_i	=	Discharge ratio or water abstraction ratio

z	=	Vertical spacing
z/h_p	=	Depth ratio
V_i	=	Velocity at the inlet of the vortex chamber
v_r	=	Radial velocity component
vt	=	Tangential velocity component
–	=	Angular spacing in degrees

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