FLOW ANALYSIS IN RIGID VEGETATION USING ANSYS

A Thesis Submitted in
Partial Fulfillment of the Requirements
for the Degree of

Bachelor of Technology
In
Civil Engineering

By

SUCHITRA BEHERA
(111CE0029)

DEPARTMENT OF CIVIL ENGINEERING
NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
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Under The Guidance of
Prof. K.K Khatua

Department of Civil Engineering
National Institute of Technology, Rourkela
Odisha-769008, May 2015

NATIONAL INSTITUTE OF TECHNOLOGY, ROURKELA
2015

CERTIFICATE

This is to certify that the project permitted "**Flow Analysis in Rigid Vegetation using ANSYS**" submitted by Suchitra Behera [Roll no. 111CE0029] in partial fulfillment of the requirements for the award of Bachelor of Technology degree in Civil engineering at the National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge the matter embodied in the project has not been submitted to any other university/institute for the award of any degree or diploma.

Date: 11.05.2015

Prof K. K. Khatua
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Place: ROURKELA **SUCHITRA BEHERA**
Date: 11.05.2015 **(111CE0029)**

ABSTRACT

Vegetation in bank of a river or stream has a major influence on resistance, velocity distribution and turbulence force. The resistance to flow in open channels depends on different channel and flow parameters. Out of many factors, vegetation is the mainly important parameter in open channels. Rigid vegetation in an straight channel change the flow of water due to the reason of energy loss during turbulence and by exerting additional drag forces on the moving liquid. Existence of vegetation in an open channel flow modify the velocity profile and the resistance in conditions of roughness coefficients.

The velocity profile and the roughness coefficients of such channels change with the flow depths and section to section. One type of vegetation is used in this study, namely artificial vegetation using iron cylindrical rods. The impact of the type of vegetation on velocity distribution of flow in an open channel (laboratory flume) was examined. The laboratory flume is rectangular in cross section and has dimensions of 12m length, 0.60m width and 0.45m depth. An ADV flow meter was used to measure the flow velocity in each section of the channel. ANSYS software was used to measure the velocity distribution from experimental data.

The results expose that inside the cylindrical rods' layer, the velocity profile no longer follows the velocity of the flow of liquid logarithmic law profile reduces within vegetated region of the channel. It is identified that the added external drag force applied by plants reduces the mean flow velocity surrounded by vegetated section of the channel comparative to non-vegetated section.

Keywords: Rigid vegetation; Velocity profile; Open channel flow; Submerged; Unsubmerged.

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CHAPTER 1

INTRODUCTION

1.1- Introduction:

Vegetation is gathering of plant collection and the ground cover they provide. Vegetation can grow naturally on the riverbanks or the beds of the channel or where it has been knowingly planted. Vegetation is categorized by its shape and the position where it grows. Vegetation increasing on the river floodplain commonly consist various combinations of herbs, shrubs, hedges, bushes, grasses and trees.

The in-channel vegetation generally consists of aquatic plants and these may be of four categories: submerged, emergent, floating leaf, and free floating. The occurrence of vegetation in river channels provides both profit and harms. From an environmental point of view, marine plants are important for natural aquatic systems and it forms the source of a waterbody's health and efficiency. From an engineering point of view, vegetation can progress the strength of bank materials through strengthening and root support.

The category of vegetation surrounded by river system has changed in latest years. The decrease in mean flow and production of turbulence stimulated by a vegetated region comparative to a non-vegetative region means that this is primary significance to flood transportation assessment, as well as to contaminant and sediment transfer.

The observable problem related to extreme growth and retardation, a decrease in hydraulic capability and flooding. Even if the flow capacity can be improved by complete or limited elimination of vegetation, this result will guide to raise in sediment loads carried by flowing water. Unobstructed growth of such vegetation in a waterway can direct to a entire loss of its hydraulic capability. Therefore, it is necessary that the equilibrium between the risk and advantage of including vegetation in channel is considered and a proper engineering conclusion be made.

The presence of vegetation contained by water passage inclines towards the rise of hydraulic resistance by dragging and disorder. Aimed at the situation of unbending foliage, the hydraulic resistance in the canal is related to performance of the channel irregularity that can be exaggerated by the existence of measurable components (e.g. cubes, cylinders).

Fig. 1 – Natural Vegetation

Fig. 2 – Artificial Vegetation (Panigrahi *et al.* 2014)

CHAPTER 2

LITERATURE REVIEW

2.1. Review of literature:

Petryk and Bosmajian (1975) for unsubmerged vegetation conditions obtained a flow resistance model. They produced a measurable technique for calculating Manning *n* value as a purpose of vegetation density and flow depth.

Thompson and Roberson (1976) established a theory to forecast the stream resistance in vegetated open canals. The concept uses small dia. cylinders to pretend vegetation irregularity components with flow state that may be either partly or completely immersed. Both of them presented an investigative technique to forecast the result of flexible vegetation on flow resistance.

Maghdam and Kouwen (1997) achieved a numerical model for assessment of irregularity for flexible and unsubmerged plants in vegetated zones and flood plain of rivers. They investigated that in the existence of foliage the Manning's *n* value rises *n* proportionately for the square root of flow deepness and in reverse reciprocal to the mean velocity for immersed conditions.

An investigational study has been conducted by **Wu et al. (1999)** using artificial irregularity to study the distinction of resistance by means of flow depth both in unsubmerged and submerged situations. Kao and Barfield (1978) completed their study to forecast the flow hydraulics for vegetated channels.

Fischenich (2002) investigated that vegetation mostly increases flow resistance or roughness. The normal water speediness at a canal cross-section inclines to reduction, due to flow resistance form the leaves and the stems of vegetation. The main effect of vegetation in the channel is on the velocity of the flow.

Righitii and Armanini (2002) investigated that the vegetation result differs seasonally. Vegetation in dry season gives more resistance of flow i.e. partially submerged as compared with vegetation in the wet season.

Wilson et al. (2003) in an open channel flow examined the result of bendable vegetation. Two changed pattern of foliage were used: a) bendable rods (strips) of continuous tallness and b) the equal rods through a branch vegetation attached. An ADV (Acoustic Doppler Velocimeter)was used to calculate the turbulent characteristics and velocity. Outcomes presented that in the presence of vegetation, the mean speed are reduced comparatively in the case of absence of vegetation. This advises that areas which are predisposed to scour and erosion, more viscous with vegetation may deliver improved safety comparative to the non-vegetated matching part.

Jarvela (2005) examined the flow arrangement beyond flexible vegetation. Velocity and turbulence features were measured with ADV (Acoustic Doppler Velocimeter). Consequences found so that flow beyond wheat go behind a logarithm law. The extreme principles for the turbulence strength and shear stress be establish about at the height of the extreme detected cover up plant rise.

Carollo et al. (2005) showed experimentations in a straight channel requiring a platform Sheltered with vegetation like grass for analysis of flow resistance for flexible underwater elements. He established that a flow opposition comparison, connecting the resistance feature with shear Reynolds number.

K. Panigrahi, K. K. Khatua (2014) showed experimentation in in straight open channel flow using rigid foliage to study the effect of vegetation in unbending cylindrical rods. The result of rising unbending vegetation on the calculation of the actual vegetal drag coefficient, Cd for numerous stream deepness arrangements has been developed.

CHAPTER 3

OBJECTIVES

Objectives of the present study:

The objective of this present work includes determination of various hydraulic characteristics i.e. velocity offered to the flow by the vegetation both in submerged and unsubmerged condition and effect of the vegetation on the flow characteristics in the channel.
The present study concentrates on the following feature:

1. To conduct the experimentation open channel flow using rigid vegetation.

2. To study the use of ANSYS (Analysis software) to predict the flow of rigid vegetation in an open channel flow.

3. To study the velocity distribution curve of an open channel flow using rigid vegetation.

4. To compare the velocity contour distribution from ANSYS with velocity contour distribution of SURFER software.

CHAPTER 4

EXPERIMENTAL SET UP AND PROCEDURE

4.1 Experimental layout:

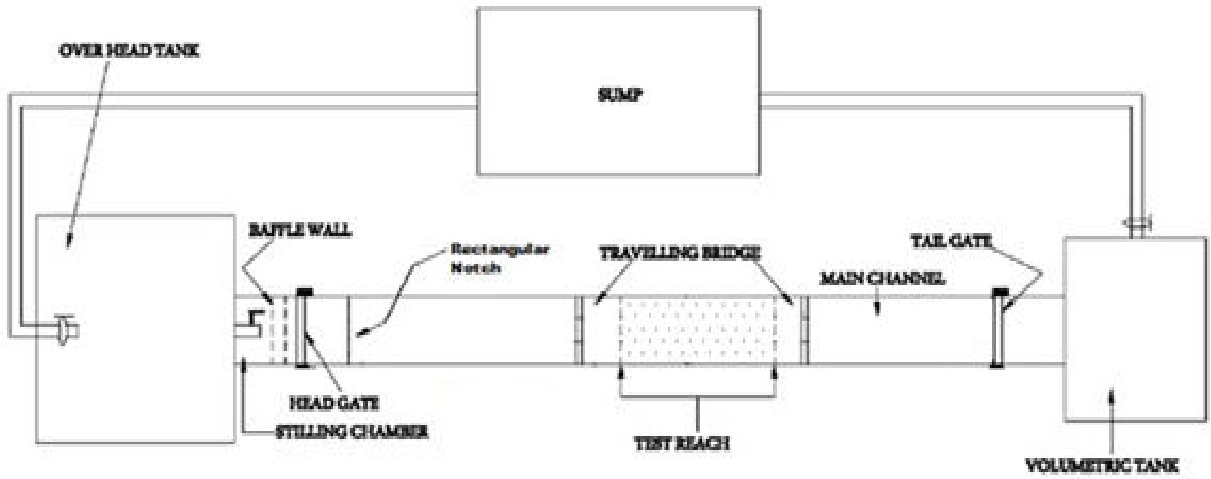

Fig. 3 – Layout of the experimental setup (Panigrahi *et al.* 2015)

4.2. Experimental Setup:

4.2.1. Flume:

Experiments were conducted in simple rectangular channel with cross section built inside a flume measuring 12m×0.6m×0.45m. The whole channel was fabricated by using 19 mm thick water resistant plywood in bed. Iron rods of diameter 6.5 mm, each raised to a height of 10 cm were pre-drilled into the plywood in a staggered pattern with spacing of 10 cm. Section of study with vegetation was limited to 6m (Panigrahi,2015).

Water will be supplied through centrifugal pumps (15 hp) discharging into a RCC overhead tank. Pump delivers water from the overhead tank to the flume with the maximum discharge of $0.047 m^3/s$.

- The aspect ratio is δ = **5.80.**
- Slope of the channel bed is **0.00101.**

Fig.4. Experimental flume (K.Panigrahi 2015)

Fig.5. Experimental flume with unsubmerged flow (Panigrahi *et al.* 2015)

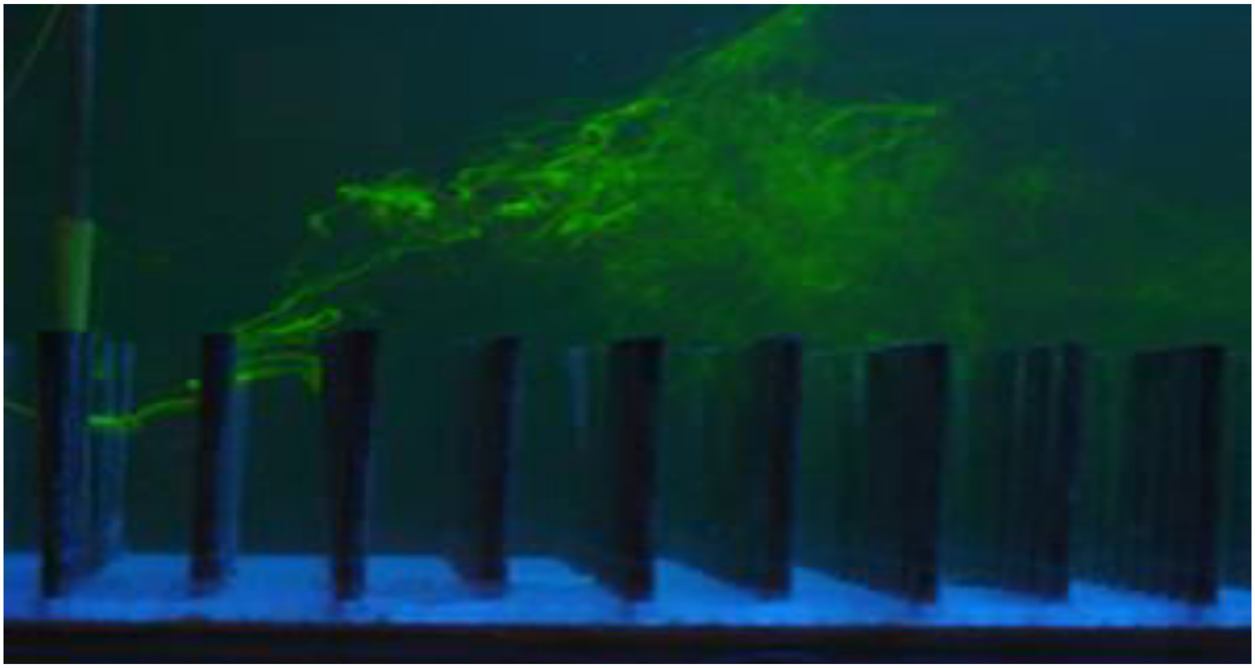

Fig.6. Experimental flume with submerged flow

4.2.2. Volumetric tank:

Volumetric tank stores the water coming out of the channel for a momentary phase of time. The volumetric tank helps us to calculate the discharge (Q) and thus the actual discharge volume of water.

Let the time required for 1cm water rise be‘t’.

Let A= Area of volumetric tank= 20.93 m^2.

Then the volume of water in‘t’ time, V = A×0.1 m^3

Then discharge (Q) = V/t m^3/s.

Fig. 7 – Volumetric Tank in the channel (K. Panigrahi 2015)

4.2.3. Arrangement of cylindrical rods in a straight open channel flow:

Iron rods of diameter 6.5 mm, each elevated to a height of 10 cm were pre-drilled into the plywood in a staggered pattern with spacing of 10 cm. Section of study with vegetation was limited to 6m.

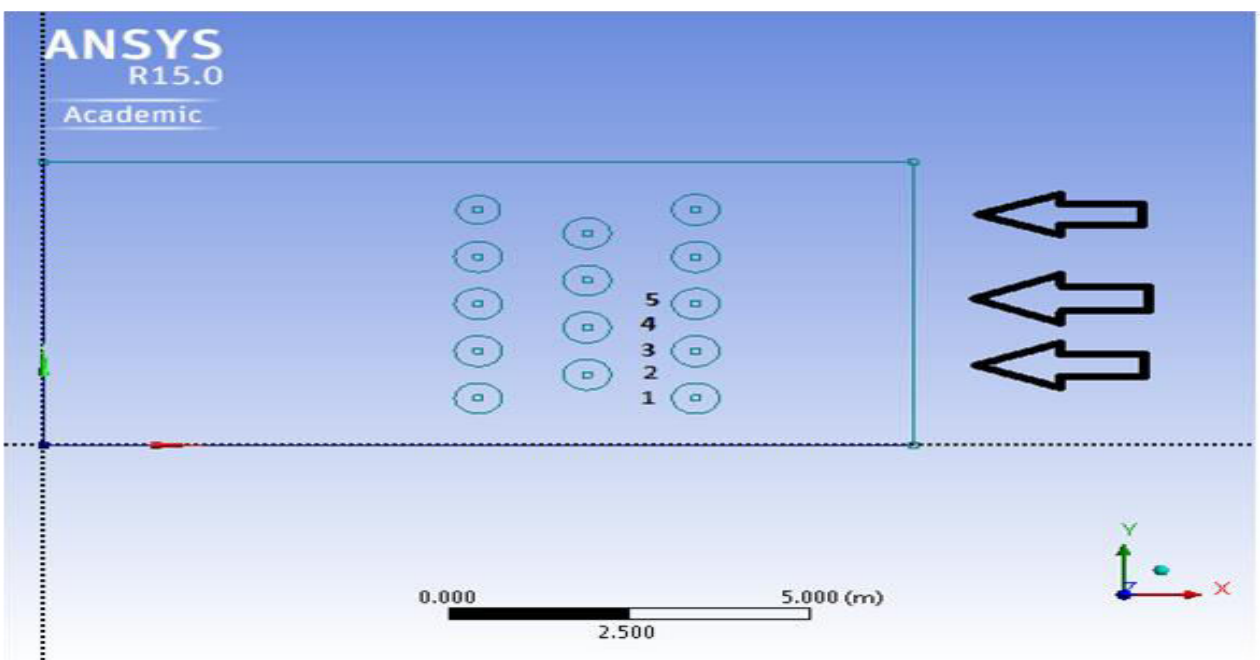

Fig.8 –Arrangement of iron rods in the rectangular channel

4.3. Apparatus and instruments used:

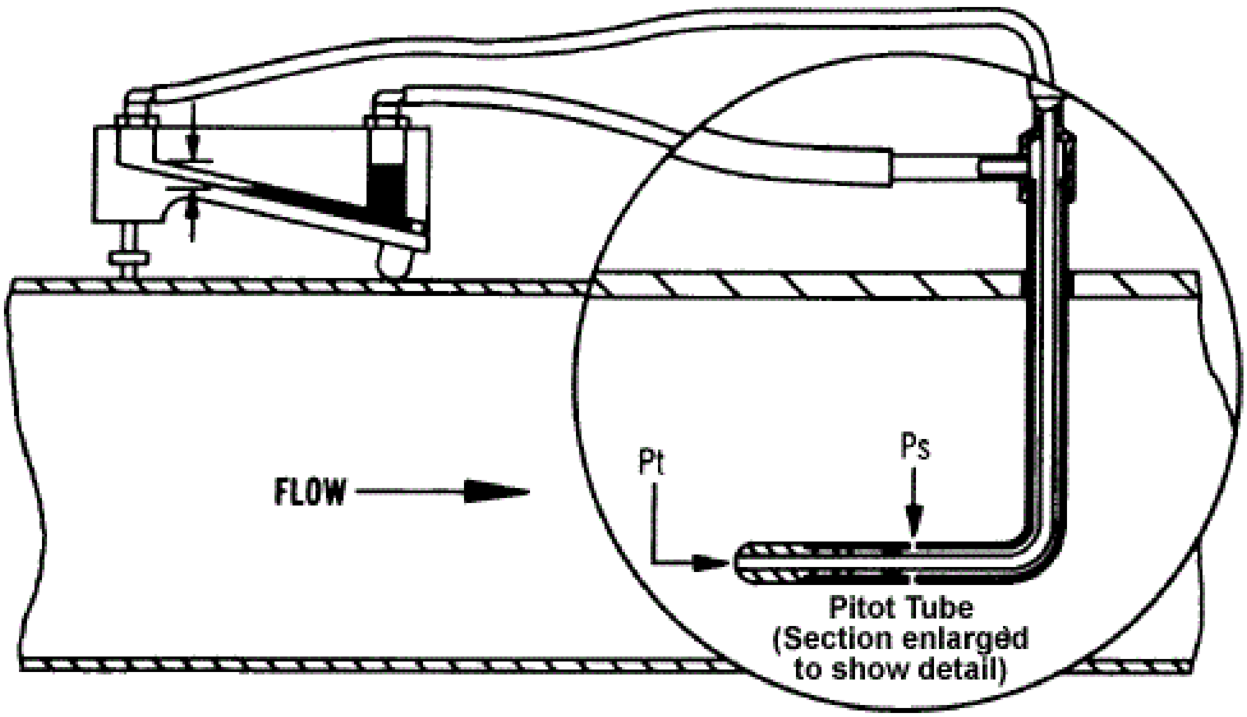

Fig.9 – Pitot tube

Measurement of velocity at experimental sections is carried out using pitot tube.

A pitot tube is a pressure determining instrument utilizes to determine liquid flow velocity. It is used to determine the flow velocity at an identified position in the flow stream. It is not used to measure the average flow velocity of the conduit or pipe. Pitot tube is joined to manometer with dynamic and static gauges.

Total pressure = Static pressure + Dynamic pressure

Point gauges were connected at two positions of the channel to check the depth of flow of water.

4.4. Experimental procedure:

In the setup of rectangular open channel with rigid vegetation, five locations at one experimental section were chosen. Point velocities were taken at the grid points. The grid points in an experimental section are spaced horizontally at the distance of 5cm each from the inner wall of the channel upto 30cm (i.e. 0cm, 5cm, 10cm, 15cm, 20cm, 25cm and 30cm). Pitot tube was used to take velocities at these points which were connected to two piezometric heads through bendable pipes. One piezometer read total head and another piezometer read static head and their difference in reading is directly relative to the point velocity. Pitot tube was placed from one point to another point by a roller and a hand operated revolving apparatus. Stable standardized discharge was maintained to run the experiment and several runs were conducted with relative depth varying between 7cm to 22.6cm.

Velocity can be found by the formula, $V = \sqrt{2gh} \sin\theta$

Where, $g = 9.81\ m/s^2$ (acceleration due to gravity)

h = Total pressure – Static pressure

θ=Angle of inclination = 33^0

Discharge is calculated at the end of the tank using glass tube indicator and volumetric tank. Water falls into volumetric tank from outlet and the rise in water is noted by glass tube indicator. The experiment was done in two depths one is submerged at 8cm depth and another is unsubmerged at 19.2cm depth.

CHAPTER 5

NUMERICAL MODELLING

ANSYS (Engineering simulation software) used by engineers worldwide in virtually all fields of engineering. Here, the use of ANSYS software is to find the velocity contour at different depth of flowing water at different velocity of the water. Use of ANSYS software is gaining popularity in an exponential rate due to its easy adaptableness and cost efficiency because it avoids the costly experimental setups. It also involves zero human error. It reduces experimental risks by providing effortless simulations. In, the present work an effort has been made to examine the velocity contour at different distance of the rigid vegetative channel.

Fig.10 - ANSYS software

5.1. Turbulence models:

The naturally occurring straight open channel flow with rigid vegetation are generally turbulent in nature. This unsteady motion of fluid can be determined as an irregular flow which is often unstable. CFD turbulence model are:

1. K- € model.
2. RNG K- € model.
3. K - ω model.
4. SST scale adaptive simulation (SAS) turbulence model.
5. K-ω Reynolds stress.
6. DES (Detached eddy simulation) turbulence model.
7. Smagorinsky LES (large eddy simulation) model.
8. Realisable K- € model.

5.2. Governing equation:

The governing equation used in this simulation is K-€ turbulence model and RNG K-€ turbulence model. This model is used to determine the mean flow nature for unsteady flow situation. This model is poor in such cases such as rotating flows, flow in circular ducts and unconfined flows. The two model involves two partial differential equations where K is the turbulent kinetic energy and € is the dissipation of energy.

The partial differential equations for K-€ turbulence model:

1. For turbulent kinetic energy K:

$$\frac{\partial(\rho k)}{\partial t} + \frac{\partial(\rho k u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_k}\frac{\partial k}{\partial x_j}\right] + 2\mu_t E_{ij} E_{ij} - \rho\epsilon$$

2. For dissipation €:

$$\frac{\partial(\rho\epsilon)}{\partial t} + \frac{\partial(\rho\epsilon u_i)}{\partial x_i} = \frac{\partial}{\partial x_j}\left[\frac{\mu_t}{\sigma_\epsilon}\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}2\mu_t E_{ij} E_{ij} - C_{2\epsilon}\rho\frac{\epsilon^2}{k}$$

Where,

$$\mu_t = \rho C_\mu \frac{k^2}{\epsilon}$$

The partial differential equation for RNG K-€ turbulence model:

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho\epsilon$$

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_\epsilon}\right)\frac{\partial \epsilon}{\partial x_j}\right] + C_{1\epsilon}\frac{\epsilon}{k}P_k - C_{2\epsilon}^{*}\rho\frac{\epsilon^2}{k}$$

Where,

$$C_{2\epsilon}^{*} = C_{2\epsilon} + \frac{C_\mu \eta^3 (1 - \eta/\eta_0)}{1 + \beta\eta^3} \qquad \eta = Sk/\epsilon$$

CHAPTER 6

NUMERICAL SIMULATION

6.1. Methodology:

ANSYS 13.0 version is used for modeling and velocity contours of the rectangular channel with rigid vegetation.

6.1.1. Preprocessing:

Geometry of the given channel was created using ANSYS workbench tool in ANSYS software. A frame of reference was chosen for the geometry for coordinate axes. Geometry was such that X-Y plane was parallel to the cross section of channel. Direction of flow was in the direction of Z-axis. Y-axis represented the vertical upward and X-axis represented the lateral direction of the geometry created. Then naming are given in the channel which shown in figures (fig.10, fig.11, fig. 12, fig. 13, fig.14).

A rectangular channel was created of dimension 12m×0.6m×0.45m. In the 12m long rectangular channel, the length of vegetative bed was 6m where iron rods are drilled in the staggered pattern. The diameter of iron rods were 6.5mm.

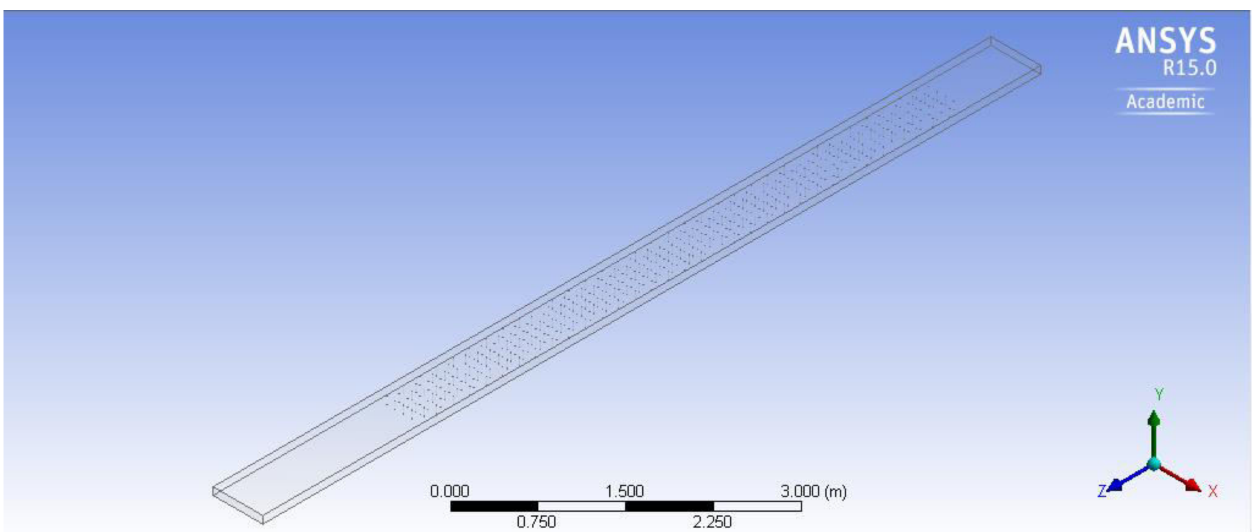

Fig.11 – Geometry of rectangular channel in ANSYS

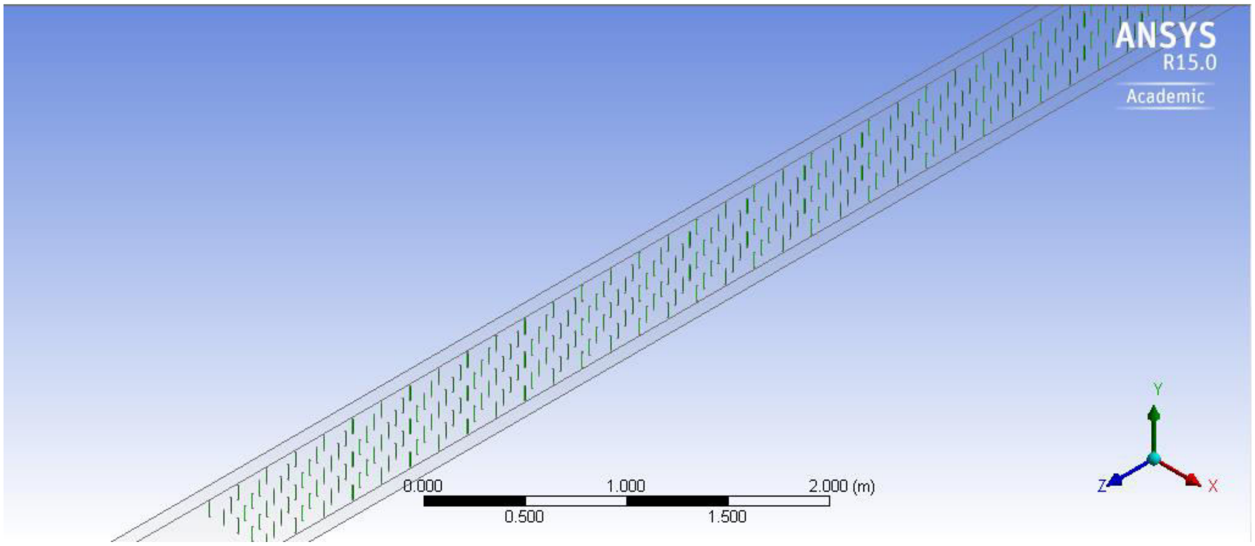

Fig.12 – Geometry of cylindrical iron rods in the rectangular channel

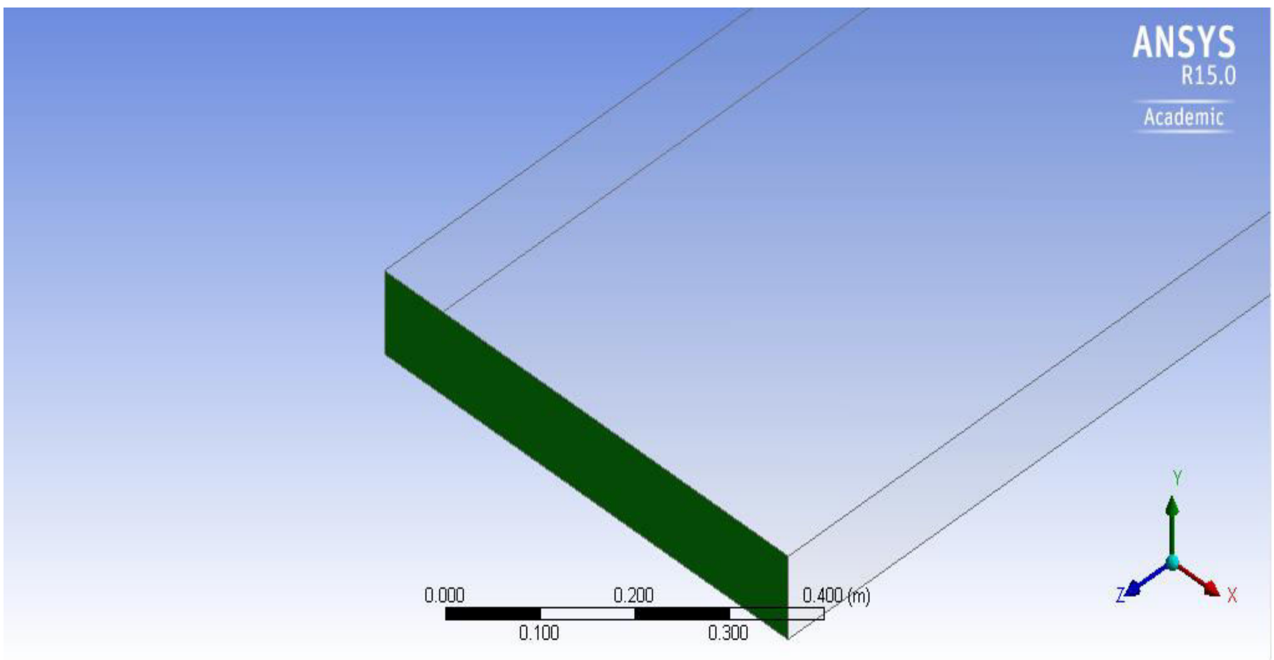

Fig.13 – Inlet of the channel

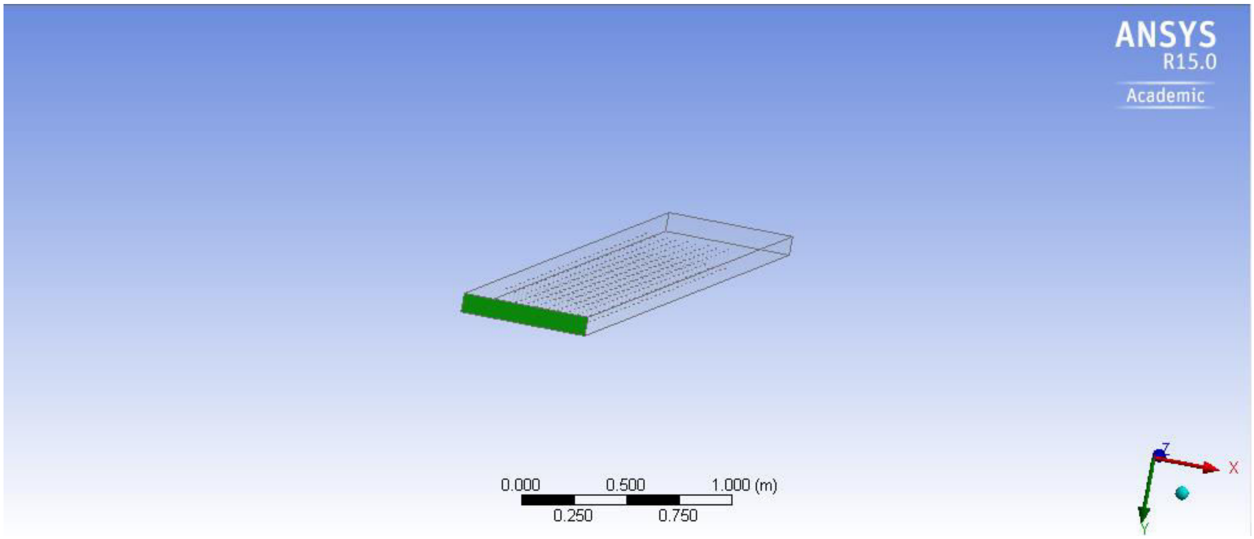

Fig.14 – Outlet of the channel

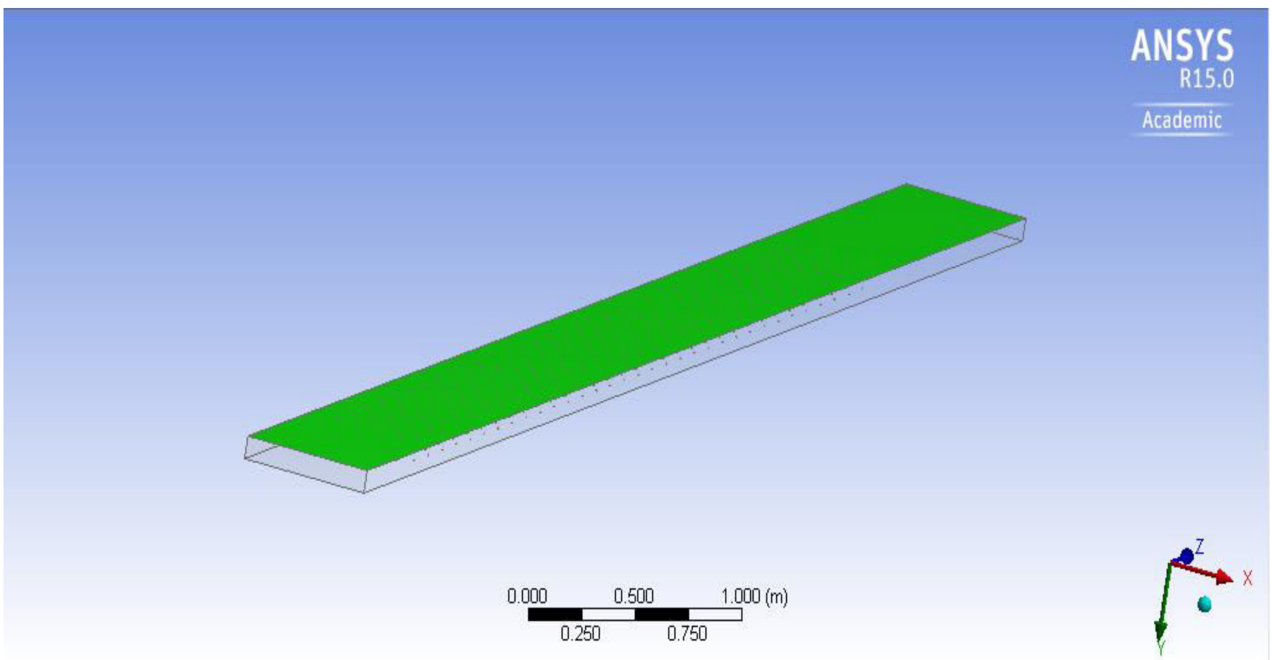

Fig. 15 – Bottom wall of the channel

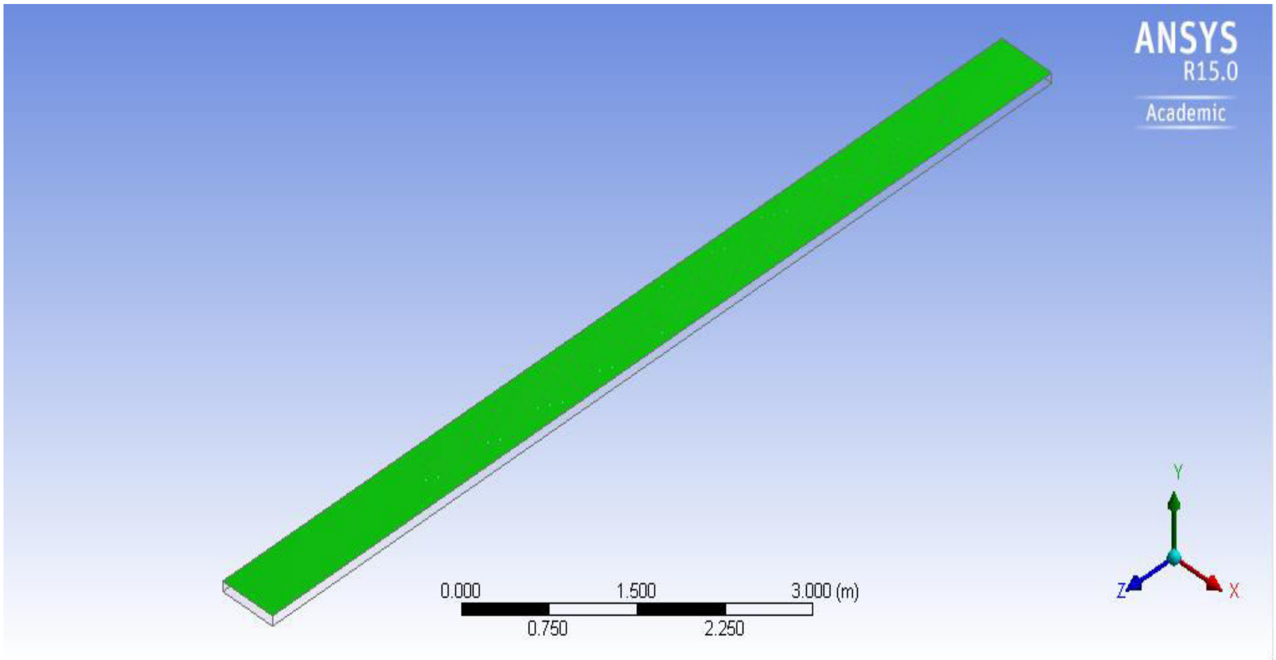

Fig. 16 – Top symmetry of the channel

6.1.2. Meshing:

Meshing was created with the help of meshing tools in workbench. Sizing of the meshing was given as an input to the meshing tool to achieve a proper discretization of the model. Fine relevance centre, high smoothing, slow transition are some preferable inputs to get a smooth meshing.

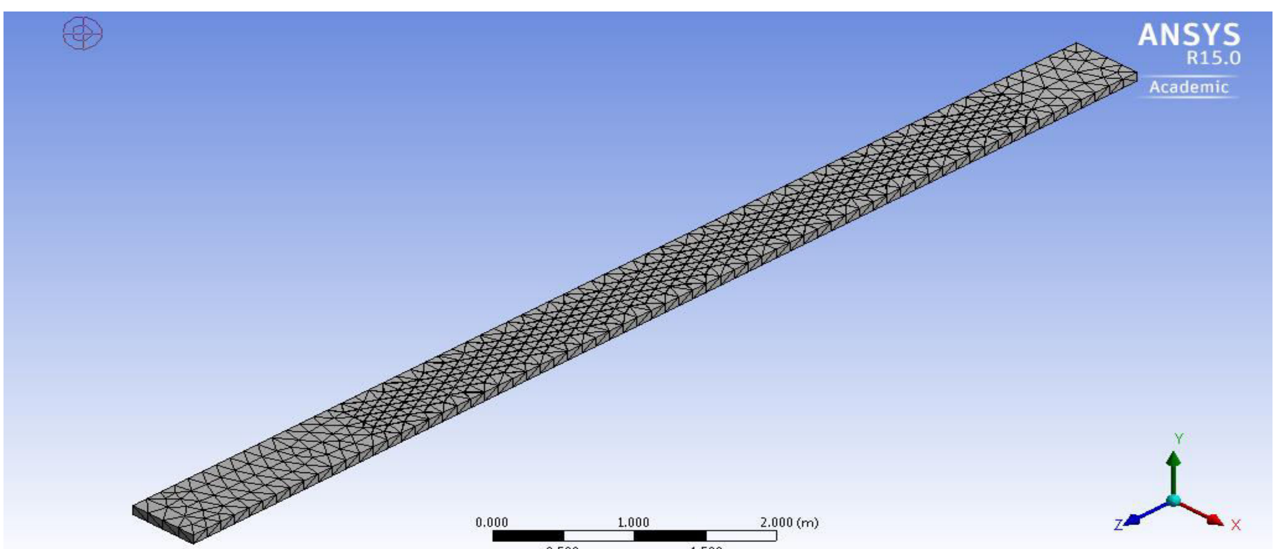

Fig.17 – Meshing of the geometry

6.1.3. Set-up:

After the meshing part is completed, various inputs are given to the Setup section. Volume of fluid is the only option for open channel flow simulation. K- Epsilon equation is applicable for viscous flow. We have to select the primary phase as air and the secondary phase as is water. The free surface level is 0.29 and the bottom level is 0.1. After giving the surface level we have to give the direction of flow, i.e. in the rectangular channel the direction of flow is in Z-axis.

After direction of flow is completed, the boundary conditions are given, i.e. the values of inlet, outlet, free surface level, bottom level, side wall, top- symmetry are given. Time steps size was set to 0.01 sec, number of time steps was set to 1000 and then the maximum iteration was given 20 for better accuracy.

CHAPTER 7

RESULT AND DISCUSSION

Point velocities at grid points of the five different cross sections are collected and the velocity contour of each cross section is plotted using software called Surfer. The velocity contour at two different distance of cross section is plotted at different velocities in ANSYS software.

7.1. Comparison of velocity contours:

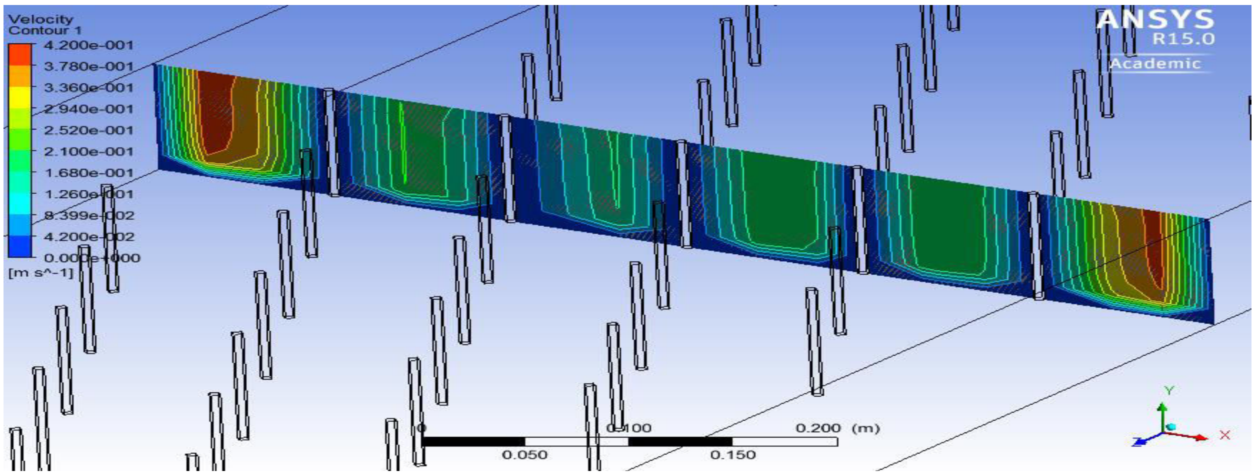

Fig.18 – Velocity contour in rigid vegetation at 8cm depth obtained by numerical analysis (Submerged condition)

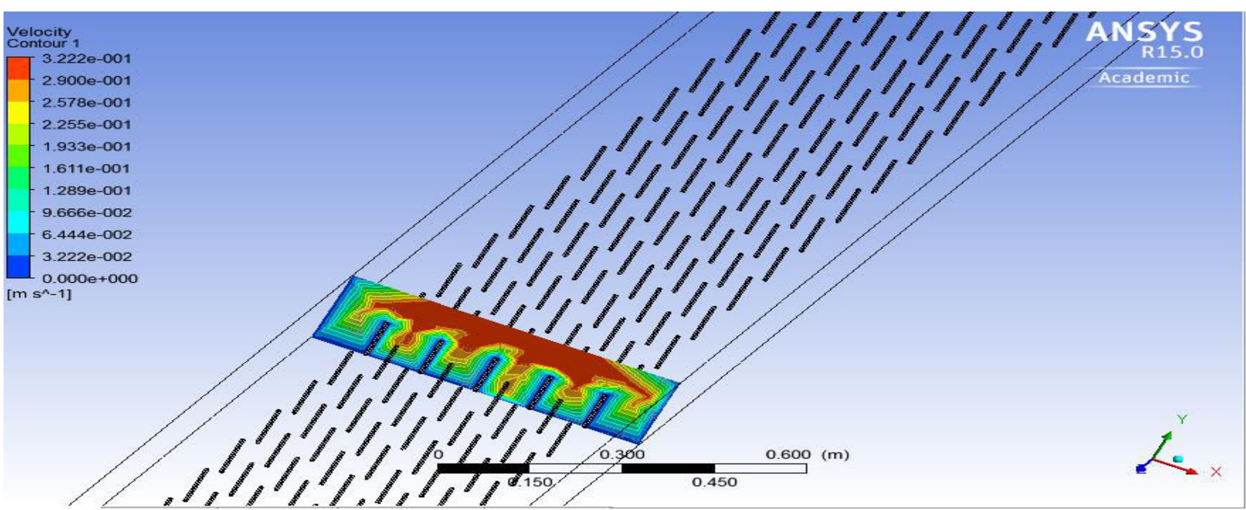

Fig.19 – Velocity contour in rigid vegetation at 19.7cm depth obtained by numerical analysis (Unsubmerged condition)

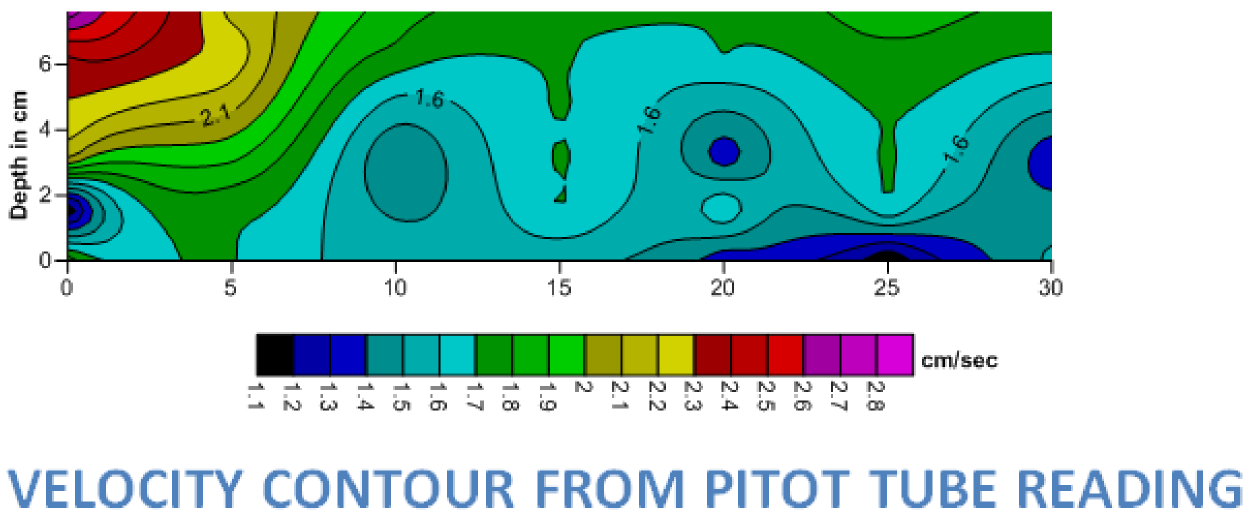

Fig.20 – Velocity contour obtained by experimental data

7.2. Comparison of vertical velocity distribution curve at the middle of the section:

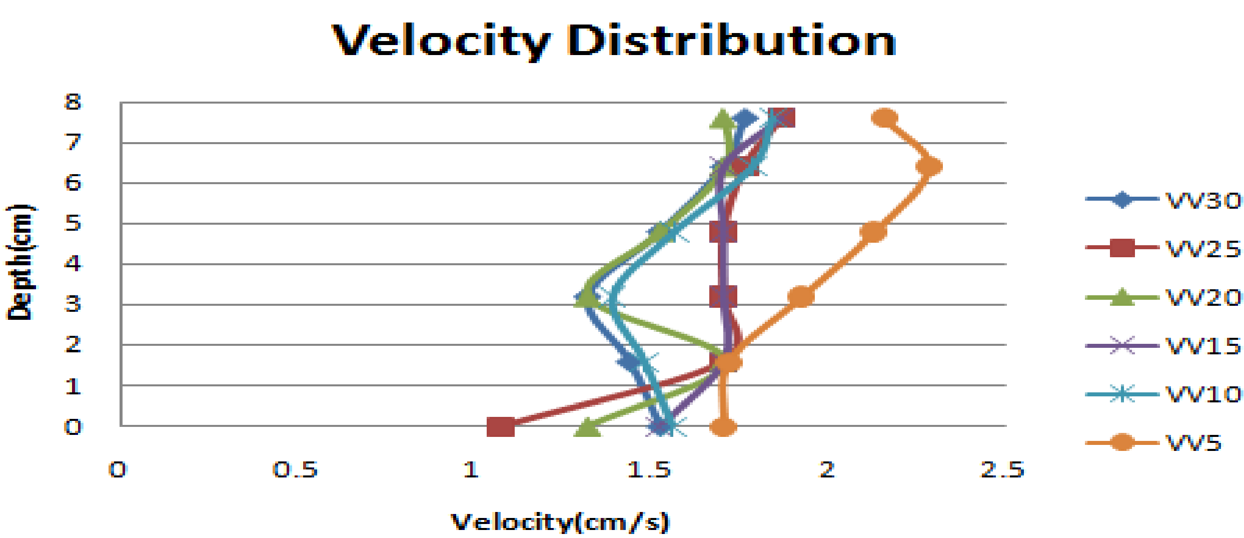

Fig.21 – Velocity distribution curve from experimental data

7.3. Discussion:

Point velocities at grid points of the three different cross sections are collected and the velocity contour of each cross section is plotted using Surfer software.

Velocity contour for both numerical and experimental data sets are compared. Form the velocity contour diagrams in figure 18 and figure 19, it was compared that the in submerged vegetation, at 8 cm depth of water the velocity of flow decreases due to presence of obstruction (i.e. rods) present in the path of flow and at the inlet of the channel, velocity of the flow increases due to turbulent nature of water and in the unsubmerged area above the cylindrical rods, at 19.2cm depth of water the velocity of the flow increases due to absence of vegetation since the height of the rods is 10cm.

Velocity contour diagram of figure 20 was found using Surfer software. In this velocity contour diagram velocity of flow of liquid gradually increase at the section where no vegetation is present. The velocity of flow is average at the middle of the channel due to presence of obstruction in the channel.

Vertical velocity distribution curve at different location is shown in figure 21. Five positions were selected named as 1, 2,3,4,5. From the velocity distribution curve it is seen that the velocity is gradually increasing while we go from bottom towards the upward, after mid depth the velocity suddenly decreases.

But for the 5th point the change in velocity is very less due to turbulence (mixing) bringing the uniformity. But at 2nd and 4th point which is present in between the rods without direct obstruction the velocity increases.

CHAPTER 8

CONCLUSIONS

8.1. Conclusions:

In the present study, the experimentation has been carried out to study the velocity profile in an straight rectangular channel using rigid vegetation. The following conclusions are drawn:

- For a straight rectangular channel the vertical velocity profile was found to increase while we go from bottom towards the upward.

- A numerical study has been done using ANSYS to predict the vertical velocity profile. A good agreement of the result from ANSYS has been found with experimental results.

- From the plot of velocities for both numerical and experimental, the velocity increases at inlet of the channel due to turbulence of liquid and at the surface where vegetation is not present and no obstruction is there.

- Similar trends were found in ANSYS and the ANSYS results were found to be in good agreement with the experimental results. ANSYS neglects the error formed by the experimental results.

- From two velocity contours it was found that the velocity of flow increases where vegetation is not present and the velocity of flow decreases where vegetation is present.

CHAPTER 9

REFERENCE

- C. A. M. E. Wilson[1]; T. Stoesser[2]; P. D. Bates[3] and A. Batemann Pinzen[4]. Open channel flow through different forms of submerged flexible vegetation, J. Hydraul. Engg. 2003.129:847-853

- Cheng, N. S., and Nguyen, H. T. (2011). "Hydraulic radius for evaluating resistance induced by simulated emergent vegetation in open-channel flows." J. Hydraul. Eng., 137(9), 995–1004.

- Ferreira, R. M. L., Ricardo, A. M., and Franca, M. J. (2009). "Discussion of 'Laboratory investigation of mean drag in a random array of rigid, emergent cylinders' by Yukie Tanino and Heidi M. Nepf." J. Hydraul. Eng. 135(8), 690–693.

- Manal M. Abood, Badronnisa Yusuf, Thamer Ahmed Mohammed and Abdul Halim Ghazali. (2006). "Manning roughness coefficient for grass lined channel", faculty of engineering, University Putra Malaysis, Suranee J. sci. Technol. 13(4): 317-330

- Li and Shen, 1973 Li, R., Shen, H.W., 1973. "Effect of tall vegetation on flow and sediment, J. of the Hydraulic Division," ASCE.

- Panigrahi. K. and Khatua. K.K. 2014. "Roughness coefficient determination in open channel flow with vegetation". INROADS- an International Journal of Jaipur National University, Vol. 3, Issue. 1, ISSN: 2277-4904, pp. 230-235.

- Panigrahi, K. and Khatua, K.K. 2015. "Prediction of velocity distribution in straight channel with rigid vegetation", Aquatic Procedia, Science Direct, Elsevier, Vol: 4, pp. 819-825.

- Panigrahi, K. and Khatua, K.K. 2015. "Analysis of different roughness coefficients' variation in an open channel with vegetation." International Conference on Technologies for Sustainable Development, IEEE, Mumbai, India.

- Panigrahi, K., Khatua, K.K. and Naik, B. 2014. "Effect of cylindrical staggered vegetation on roughness prediction in an open channel", International Journal of Scientific Engineering and Technology, ISSN: 2277-1581, pp. 207-212.

- R.G. Diaz, "Analyisis of Manning coefficient for small depth flow on vegetated beds," Hydrological processes, Vol. 19, (2005).

- Righetii and Armanini, 2002 Righetii, M., Armanini, A., 2002. "Flow resistance in open channel flows with sparsely distribution bushes," J. of Hydrology.

- W.L.Cowan, "Estimating hydraulic roughness coefficients", Agriculture engineering, Vol. 37, (1956) pp.473-475.