FLOW ANALYSIS OF RIGID AND FLEXIBLE VEGETATION USING ANSYS FLUENT

A Dissertation submitted in partial fulfilment of the requirement for the
Award of degree of

MASTER OF TECHNOLOGY

IN

HYDRAULICS AND WATER RESOURCES ENGINEERING

BY

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JULY 2017

CANDIDATES'S DECLARATION

I do hereby certify that the work presented is the report entitled **"Flow Analysis Of Rigid And Flexible Vegetation Using Ansys Fluent"** in the partial fulfilment of the requirements for the award of the degree of "Master of Technology" in Hydraulics & Water Resources Engineering submitted in the Department of Civil Engineering, Delhi Technological University, is an authentic record of my own work carried out from January 2017 to July 2017 under the supervision of Dr. Munendra Kumar (Assistant Professor), Department of Civil engineering.

I have not submitted the matter embodied in the report for the award of any other degree or diploma.

Date: 30/06/2017

Shashank Aggarwal
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CERTIFICATE

This is to certify that above statement made by the candidate is correct to best of my knowledge.

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ACKNOWLEDGEMENT

I take this opportunity to express my profound gratitude and deep regards to Dr. Munendra Kumar (Assistant Professor, Civil Engineering Department, DTU) for his exemplary guidance, monitoring and constant encouragement throughout the course for this project work. The blessing, help and guidance given by him from time to time shall carry me a long way in life on which I am going to embark.

I would also like to thank Dr. Nirendra Dev (Head of Department, Civil Engineering Department, DTU) for extending his support and Guidance.

Professors and faculties of the department of Civil Engineering, DTU, have always extended their full co-operation and help. They have been kind enough to give their opinions on the project matter; I am deeply obliged to them. They have been a source of encouragement and have continuously been supporting me with their knowledge base, during study. Several of well-wishers extended their help to me directly or indirectly and we grateful to all of them without whom it would have been impossible for me to carry on my work.

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ABSTRACT

Vegetation can be described as the collection of plant gathering, acting as a covering to the ground or the surface or banks of river. Even though the capacity of flow in the river can be improvised by completely or partially removing the vegetation, these experiments can help in identifying the hike in sediment loads that are carried by the flowing water. If obstructions are not created in the path of such growing vegetation then it might result in severe damage to hydraulic capacity. In the present study, we have performed the required experiment and verified the results by software, ANSYS FLUENT. In conducting the experiment for studying the flow in the presence of vegetation in a rectangular channel, we have used flume apparatus. The size of the flume is 6.18 m* 0.3m* 0.4m along with the size of vegetation as 6mm in diameter and 10cm in length. For rigid vegetation we have used an iron rod and an electrical wire for flexible one and in order to fulfil the energy requirements we have used a hydraulic pump of 10hp.

The results showed that the Reynold's Number obtained was seen highest for 0.4 m/s velocity for flexible vegetation, as high as 5955.8 confirming turbulence at highest discharge unlike for rigid vegetation. Froude's Number was observed from 0 to 1 for both the cases. Also, low values for Coefficient of discharge and Manning's coefficient explained low resistance offered during the flow for flexible vegetation unlike in the case of rigid vegetation where, there was much resistance offered to the flow. Lastly, Head Loss at every section was observed quite low explaining that the water lost during the experiment at every section was less.

CHAPTER - 1

INTRODUCTION

Vegetation can be described as the collection of plant gathering, acting as a covering to the ground or the surface. As this vegetation might naturally grow on the banks of river, it might spring out on the channel beds as well. Vegetation can also be planted purposely in order to serve a specific purpose. It can be classified on the basis of its shape, position or type depending upon the surrounding it develops on. Also, the type of vegetation growing on the river floodplain is categorised as shrubs, hedges, bushes, tress or grass. The type of vegetation grown cannot be developing out of a single reason but due to several ones.

Vegetation growing on the inside of the channel generally consists of some marine plants which can be divided into four categories, namely, submerged, emergent, floating leaf and free floating. The sudden or unexpected presence of this vegetation can serve as beneficial as well as harmful. In order to evaluate the pros and cons let's understand this from the fact that vegetation plays a vital role in pertaining to river's health and performing capabilities. Similarly it is beneficial for the bank materials as they can provide strength and support to roots if viewed from an engineering angle. Thus, vegetation helps in stabilising the strength, support and friction created within the river system. The kind of vegetation covering river system has seen notable changes since the last few years. This has resulted in the reduction of mean flow and turbulence generated by the region in which vegetation is grown in comparison to an area with no vegetation cover indicating that such condition is primarily significant to transport of flood and related assessment, along with contaminant transfer and sediment transfer. In lieu of this the noticeable problem observed with high growth is the decrease in efficiency of the hydraulic mechanism and sudden effect on flooding.

Also, even though the capacity of flow in the river can be improvised by completely or partially removing the vegetation, these experiments can help in identifying the hike in sediment loads that are carried by the flowing water. If obstructions are not created in the path of such growing vegetation then it might result in severe damage to hydraulic capacity. The use of vegetation in the water way is directed towards the rise in hydraulic resistance by a developed drag. Thus, this becomes a necessity that a balance between the presence and absence of vegetation is thoroughly thesised to reach a likewise conclusion. To describe, aquatic plants play a significant role in building a natural water environment and are important factors while planning river management strategies. It is important to compute the resistance to flows for proper management of river. Thus, estimating the flow resistance to vegetated flows is of great importance in river management. In order to do so certain characteristics of the open channel flow are considered such as alignment of vegetation elements like shape, size, density and also the turbulence characteristics which might affect the resistance generated. Thus it becomes important to estimate the flow resistance in river directly leaving an impact on the channel flow parameters. Referring to past studies that have been conducted it can be observed that the presence of vegetation in the channel might serve as a hindrance to flow. In addition to this, there have been many studies on river restoration and reformation. In addition, there has been a varying demand in application of numerous bioengineering methods. Therefore, in order to tackle the obstacles in river management strategies, descriptive knowledge on hydraulic variations is a necessity to redeem the laid objectives.

Some of the basic definition involved in our study are discussed below:

1.1.VEGETATION:

It is defined as plants that together grow in a particular area and offer roughness to surface, thereby reducing the volume and capacity of the flow area and deaccelerates the flow velocity.

1.2. CLASSIFICATION OF VEGETATION:

Classification of vegetation is a process which is a dense task as there are around three million species of plants to be classifies. However on a broad level they can be categorised into two main parts, natural and artificial vegetation.

When vegetation is used for waterways it is divided into two parts:

i. Natural Vegetation

The ones that can be found naturally on surface beds and on the banks of a river. This type of vegetation constitutes basically trees, herbs, bushes or grasses.

ii. Artificial vegetation

The ones that are planted to serve the required purpose on the river banks or in certain experiments to study the flow characteristics. There can be many methods to plant this type of vegetation like, cutting, layering or grafting (mainly used by farmers or gardeners).

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Fig. 1. Natural Vegetation

Fig. 2. Natural Vegetation acting as hindrance

Fig. 3. Artificial Vegetation

The extent of influence on the vegetation characteristics mainly depends upon the following:

- distribution
- vegetation species
- flexibility
- degree of submergence
- vegetation density
- vegetation height

The offered resistance and velocity profiles of channels with such vegetation in open channels tend to change with depth of flow. It is evident that little is understood about local vegetation and its related effects on low density. Also, in a channel with flow in presence of vegetation the velocity (average velocity) is bound to decrease exponentially within the channel cross section all because of the friction offered by the different forms of vegetation which indirectly is responsible for the surface roughness. Thus, there seems a need of experiments to untangle the complexities associated with such nature and develop a flow model with calculations.

Generally, the approach to compute resistance offered to flow is dependent on Manning's 'n' to a few parameters describing the conditions of flow, however nowadays the computation of resistance co-efficient is not that easy anymore, thus experiments are conducted.

In the present study, we have performed the required experiment and verified the results by software, ANSYS FLUENT. In conducting the experiment for studying the flow in the presence of vegetation in a rectangular channel, we have used flume apparatus. The size of the flume is 6.18 m* 0.3m* 0.4m along with the size of vegetation as 6mm in diameter and 10cm in length. For rigid vegetation we have used an iron rod and an electrical wire for flexible one and in order to fulfil the energy requirements we have used a hydraulic pump of 10hp.

The whole of this apparatus is maintained to analyse the change in depth and velocity, experimentally first and later through software. The analysis constitutes the computation of Reynold's Number, Froude Number, Discharge Co-efficient and Manning's Co-efficient.

1.3. OBJECTIVES OF PRESENT STUDY

This thesis focusses on the velocity distribution with rigid and flexible vegetation. The experiments are conducted in a rectangular flume with varying parameters on which the velocity is affected by. All of this is studied in an open channel with vegetation, rigid and flexible. This velocity profile is dependent upon a few parameters like depth of flow, density of vegetation, type of vegetation, height where depth of flow is the main parameter for estimating the velocity distribution.

The objectives of our thesis are laid as:

- To carry the experiments in a rectangular flume with rigid and flexible vegetation to compute:

  (a) Reynolds number (R_e)

  (b) Froude number (F_r)

  (c) Head loss (H_L)

  (d) Coefficient of Discharge (C_d)

  (e) Roughness coefficient (C_r)

- To analyse the effect of velocity distribution in the flume.
- To use a software to compute and then verify the results of experiments on velocity distribution using Ansys Fluent.

- To validate and verify the results of experiments like velocity profile with software procedures.

1.4. ANSYS FLUENT

The software used in our thesis is ANSYS Fluent (R15.0) which is one of the most significant computational fluid dynamics (CFD) software tool that enables us to perform the calculations at a better and speedy rate. This software also specializes in CFD Simulation, also known as CFD modeling which is helpful in solving different engineering procedures and specifically, for our study, velocity distribution profile formation. The emerging interest on the use of CFD based simulation by engineers has long been analyzed in various fields of engineering. The basic principle in the application of CFD is to determine fluid flow in-detail by solving a system of nonlinear governing equations over the region of interest, after applying specified boundary conditions. The CFD based simulation confides on combined numerical accuracy, modeling precision and computational cost.

Using ANSYS CFD, the system of fluid flow can be virtually simulated using a computer. One can start analysing by making a mathematical model of physical system. The CFD approach comprises of 3 methods Finite Difference Method, Finite Volume Method and Finite Element method.

1.4.1 Advantages of CFD

I. It lowers the cost of simulation and the geometry can be changed as many as times till the accurate result is obtained.

II. It can perform simulations at much high speed with error margin neglible.

III. It can make the model to work at real conditions which is very difficult to make in experimental models.

1.4.2 Limitations of CFD

I. The model results are totally based on physical model so it should be made correctly.

II. The accuracy of model is perfect till the given initial and boundary conditions are good.

1.5. ORGANIZATION OF THESIS

The thesis comprises of a total 5 chapters where, *Chapter 1* describes the role of rigid and flexible vegetation, about the software ANSYS and the objectives of the study. *Chapter 2* lays out the review of literature available on our field of study. *Chapter 3* talks about the experimental set up and procedure adopted. Results and Discussion on the study are listed in *Chapter 4* and *Chapter 5* deals with the conclusions and scope of the work in future.

CHAPTER - 2

LITERATURE REVIEW

1. **Meftah et al. (2006)** explained in their study the understanding and studying of the vegetation effect on the natural water flows is an important objective in modern scientific thesis about river management and restoration, with high environmental impact. Therefore, the effect of a rigid and flexible vegetation, with a characteristic low density, on a transversal current was analyzed in a laboratory flume. Different configurations as vegetation type, flow depth and velocity were investigated, always keeping the vegetation submerged. 3D velocity components and turbulence characteristics, such as turbulence intensity and Reynolds stresses, were conducted at different measurement points by the Acoustic Doppler Velocimeter (ADV) system. The velocity and turbulence parameters profiles and distributions were plotted in horizontal and transversal section, in order to quantify the effect of the two kinds of vegetation on the crossflow. The results showed a local behavior, in the range of mms, due to the particular low vegetal density that do not allow to consider the flow field within the vegetation homogeneous at the stem scale. The experimental results for the rigid vegetation were compared to the results for the flexible one, showing a more definite deceleration of the flow and increase of the turbulence in the first case under the top of the vegetated layer.
2. **Busari et al. (2015**) elaborates about submerged vegetation is a key component in natural and restored rivers. It preserves the ecological balance yet has an impact on the flow carrying capacity of a river. The hydraulic resistance produced by submerged flexible vegetation depends on many factors, including the vegetation stem size, height, number density and flow depth. In the present work a numerical model is used to generate synthetic velocity profile data for hydraulic roughness determination. In the model turbulence is simulated by the Spalart-Allmaras closure with a modified length scale which is dependent on the vegetation density and vegetation height to water depth ratio.

Flexibility of vegetation is accounted for by using a large deflection analysis. The model has been verified against available experiments. Based on the synthetic data an inducing equation is derived, which relates the Manning roughness coefficient to the vegetation parameters, flow depth and a zero-plane displacement parameter. Furthermore, the uncertainty of the inducing equations in the estimation of the Manning roughness is assessed and the propagation of the uncertainty due to the variability of the vegetation and flow parameters existed in nature is investigated by using the method of Unscented Transformation (UT). The UT is found efficient and gives a more accurate estimation of the mean Manning roughness coefficient and provides information on the covariance of the roughness coefficient.

3. **Yiping et al. (2015)** shows flexible emergent vegetation has a remarkable impact on flow structure, flood control and ecological restoration. In this study, the variation of flow turbulence and kinetic energy characteristics caused by artificial flexible emergent vegetation were studied by measuring the flow velocity with a 3D acoustic Doppler velocimeter (ADV) in an open flume. Experiments were carried out in five vegetation densities at two flow discharges, which commonly occur in rivers. The findings revealed that flexible emergent vegetation had a great resistance on flow to quickly reduce the average velocity, especially at the foliage part. In vegetation zone, vertical velocity profiles were roughly divided into two layers: the upper layer ($z/z0 > 0.3$) and the bottom layer ($z/z0 < 0.3$). The demarcation line of foliage and sheath stem ($z/z0 = 0.3$) were observed to be a key point to impact the Reynolds stress, turbulence intensity and turbulence kinetic energy. This area was the momentum exchange area, turbulence and Reynolds stress increased gradually along with the streamwise distance. At the same time, the larger vegetation density, the greater turbulence momentum exchanged. The experiment also measured Manning's coefficient n and obtained that vegetation density was a more important factor to influence roughness than flow discharge. A linear relationship was obtained between vegetation density and Manning's n. The findings in this paper will be useful for understanding the impact of emergent vegetation on the flow pattern, flood control and designing aquatic vegetation restoration.
4. **Huai et al. (2009)** summarizes previous studies on the flow in open channels with rigid vegetation, and constructs a mathematical model for submerged and emerged rigid vegetation. The model involves the forces balance in the control volume in one-dimensional steady uniform flow. For submerged vegetation, the whole flow is divided into four regions: external region, upper vegetated region, transition region and viscous

region. According to the Karman similarity theory, the article improves the mixing length expression, and then gives an analytical solution to predict the vertical distribution of stream-wise velocity in the external region. For emerged vegetation, the flow is divided into two region: outer region and viscous region. In the two circumstances, the thicknesses of each region are determined respectively. The comparison between the calculated results and our experimental data and other thesisers' data proves that the proposed model is effective.

5. **Panigrahi et al. (2105)** explores the effect of vegetation in terms of rigid cylindrical roughness on the hydraulics of flow in an open channel is presented. The study consists of an extensive set of flume experiments for flows with unsubmerged rigid cylindrical stems of various concentrations arranged in regular staggered configurations. The study will be helpful for finding roughness and local velocity in a channel with rigid vegetation. The effect of emergent rigid vegetation on the prediction of the effective vegetal drag coefficient, Cd for various flow depth combinations has been explored. Vegetal drag coefficient Cd is found to vary with the non-dimensional hydraulic, geometric and surface parameters such as vegetation densities, relative depth ratio of water depth h to plant height hs, Reynolds's number Re and Froude's number Fr etc. The suitable dependencies of the vegetal drag for the non-dimensional hydraulic and geometric parameters are presented. Analysis and comparisons with flexible vegetation has also been done with the present experimental work on rigid vegetation. Parameters affecting the velocity drag coefficients for both the cases are discussed, compared and results are summarized and presented.
6. **Jarvela et al. (2002)** discuss about the flow resistance of natural grasses, sedges and willows which were studied in a laboratory flume. The objective was to investigate, how type, density and placement of vegetation, flow depth and velocity influence friction losses. The plants were studied in various combinations under non-submerged and submerged conditions in a total of 350 test runs. The results show large variations in the friction factor, *f*, with depth of flow, velocity, Reynolds number, and vegetative density. The friction factor was dependent mostly on the relative roughness in the case of grasses, the flow velocity in the case of willows and sedges/grasses combined, and the flow depth in the case of leafless willows on bare bottom soil. Leaves on willows seemed to double or even triple the friction factor compared to the leafless case despite the fact that the bottom was growing sedges in both cases. For the leafless willows, *f* appeared to increase with depth almost linearly and independently of velocity. Unexpectedly, different spacing

of the same number of leafless willows with grasses did not have any significant effect on *f*. Based on the experimental work, a better understanding of flow resistance due to different combinations of natural stiff and flexible vegetation under non-submerged and submerged conditions was gained.

7. **Kothiyari et al. (2009)** shows results of an experimental study on the drag force measurement involving a single stem kept in a channel flow stem array are presented. The data collected herein and those from literature indicate that the stem drag coefficient logarithmically increases with the areal stem density. The stem Reynolds number is noticed to have only a small effect on the stem drag coefficient which was however found to depend on the stem staggering pattern. The drag coefficient is less influenced by the Froude number in subcritical flows but it decreases with the Froude number in supercritical flows. New relationships are proposed for the stem drag coefficient which appear useful in partitioning the total flow resistance of vegetated bed streams into the stem and the bed particle resistances. The bed particle resistance applies to sediment transport through such vegetated flows for which the average flow velocity is available.
8. **Aberle et al. (2013)** summarizes current practices for the estimation of flow resistance caused by floodplain vegetation in emergent flow conditions. The current state-of-the-art for the parameterization of vegetative form drag and associated flow resistance was explored with a view on practical applicability. Specifically, the dissimilar resistance behaviour of simply shaped rigid elements and foliated natural vegetation was emphasized by compiling and reanalysing data published by the authors' thesis teams as well as others. It was shown that describing the key hydraulic properties of plants, geometry, and flexibility, with species-specific parameters is superior to the rigid cylinder analogy commonly used in hydraulic engineering practice. The discussion on the limitations of many existing approaches for the determination of vegetative flow resistance is intended to advance the use of modern practices such as the parameterization of vegetation density with the leaf area index, a parameter that can be derived using remote sensing techniques.
9. **Behera (2015)** speaks about 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 rigid vegetation using iron 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 un-vegetated section.

10. **Tsavdaris et al. (2013)** investigates the accuracy, applicability, and suitability of two different numerical modelling approaches available in Ansys Fluent 12.1 for the study of flow in detention ponds with emergent vegetation by making use of experimental results obtained in a laboratory flume. The aim of this investigation is to formulate an automated firstorder approximation technique that could be used as part of an urban drainage model; such an approach could be an accurate yet practical technique for modelling the effects of vegetation in ponds at pre-construction stage in the interests of predicting general flow patterns. Using the actual vegetation density of a surface water detention pond located at Waterlooville, Hampshire, UK, replicated in a laboratory flume, two different Computational Fluid Dynamics modelling strategies were tested. The first involved the specification of the individual stems within the computational domain, and these results showed very good agreement with experimental data. In the second approach, a porous zone condition was applied in the vegetated region, and here the results seem to be appropriate for predicting general flow arrangements, though without being hydro-dynamically as accurate as the first approach.
11. **Huai et al. (2014)** explores on The effect of submerged flexible vegetation on flow structure (e.g. flow velocity, Reynolds shear stress, turbulence intensity and Manning coefficient) was experimentally studied with a 3D Acoustic Doppler Velocimeter (ADV) in an open-channel flume. The results from flow observations over artificial plants (designed to simulate natural vegetation) showed that flow structure was affected

markedly by the presence of submerged flexible vegetation. The study provides understanding of flow patterns, variation in velocity profile and turbulence structures that are affected by plant stem density. The study also reveals how the flow patterns return to stability at the downstream end of the vegetated area which is critical in determining the length of the vegetated areas for restoration cases. Also, new mathematical expressions (equations) have been formulated to clearly express variations in velocity profile, Manning coefficient and flow discharge ratio with vegetation density. Vertically, the velocity profile could be roughly divided into three layers, including the upper non-vegetated layer, the middle canopy layer, and the lower sheath layer. In the upper non-vegetated layer, velocity profiles followed the logarithmic law, and a corresponding empirical equation was developed based on the observed data. The flow is from left to right in this study, and the velocity profile followed a left round bracket "(" with the minimum point located at the canopy area ($0.7H_v$, where H_v denotes vegetation height) within the middle canopy layer. However, the velocity profile followed a right round bracket ")" in the lower sheath section layer with the maximum point located at the sheath section ($0.2H_v$). With increasing vegetation density, the velocity and corresponding flow rate increased in the upper non-vegetated layer and decreased within the middle canopy layer and the lower sheath layer. The ratio of average flow discharge in the non-vegetated and vegetated layers followed the exponential function law with increasing vegetation density. This analysis revealed the effect of vegetation on flood potential and flow bottom scour. Reynolds stresses peaked above the canopy top ($z/H_v = 1.0–1.2$, here z denotes vertical coordinate), and the turbulence intensities reached their maximum peak at two locations including the sheath section ($z/H_v = 0.1–0.4$) and the canopy top ($z/H_v = 1.0–1.6$) for all vegetation densities. Manning coefficient was highly correlated to vegetation density and inflow rate with new empirical equations being proposed.

12. **Wilson et al. (2003)** talks about laboratory experiments are used to explore the effect of two forms of flexible vegetation on the turbulence structure within a submerged canopy and in the surface flow region above. The two simulated plant forms involve flexible rods (stipes) of constant height, and the same rods with a frond foliage attached. These plant forms were arranged in a regular staggered configuration, set at the same stipe density. The plant geometry and its mechanical properties have been scaled from a real aquatic plant using Froudian similarity, and the methods used for quantifying the bending stiffness, flexural rigidity, and drag force–velocity relationship of the vegetation are outlined. Experimental results reveal that within the plant layer, the velocity profile no

longer follows the logarithmic law profile, and the mean velocity for the rod/frond canopy is less than half of that observed for the simple rod array. In addition to the mean flow field, the turbulence intensities indicate that the additional superficial area of the fronds alters the momentum transfer between the within-canopy and surface flow regions. While the frond foliage induces larger drag forces, shear-generated turbulence is reduced due to the inhibition of momentum exchange by the frond surface area. It is known that the additional drag exerted by plants reduces the mean flow velocity within vegetated regions relative to un-vegetated ones, but this thesis indicates that plant form can have a significant effect on the mean flow field and, therefore, potentially influence riverine and wetland system management strategies.

13. **Folkard (2011)** shows analysis of results from laboratory flume experiments are presented in which flow within gaps in canopies of flexible, submerged aquatic vegetation simulations is investigated. The aims of the work being to identify the different flow regimes that may be found within such gaps, using Morris' classical definitions of skimming flow, wake interference flow and isolated roughness flow as a template, also, to determine the parameter space in which those flow regimes are most consistently delineated and to provide quantitative measurements of the loci of each flow regime within that parameter space for these experiments. The sedimentary and biological implications of each flow regime are also discussed. The results show that five flow regimes may be identified, expanding on Morris' original set of three. The five, namely, skimming flow, recirculation flow, boundary layer recovery, canopy through-flow, isolated roughness flow, the last being assumed to occur in some cases though it is not directly observed in these experiments. A Reynolds Number based on the canopy overflow speed and the gap depth, and the gap aspect ratio are found to be the key parameters that determine these flow regimes, though a Froude number is found to be important for determining bed shear stress, and the length of leaves overhanging the gap from the upstream canopy is found to be important in determining the location of flow recirculation cells within the gap.
14. **Wu (2008)** shares about the flow resistance factors of non-submerged rigid vegetation in open channels were analyzed. The formulas of drag coefficient C_D and equivalent Manning's roughness coefficient n_d were derived by analyzing the force of the flow of non-submerged rigid vegetation in open channel. The flow characteristics and mechanism of non-submerged rigid vegetation in open channel were studied through flume experiments.

15. **Righetti (2017)** addresses the problem of the resistance due to vegetation in an open channel flow, characterized by partially and fully submerged vegetation formed by colonies of bushes. The flow is characterized by significant spatial variations of velocity between vertical profiles that make the traditional approach based on time averaging of turbulent fluctuations inconvenient. A more useful procedure, based on time and spatial averaging (Double-Averaging Method) is applied for the flow field analysis and characterization. The vertical distribution of mean velocity and turbulent stresses at different spatial locations has been measured with a 3D Acoustic Doppler Velocimeter (ADV) for two different vegetation densities where fully submerged real bushes (salix pentandra) have been used. Velocity measurements were completed together with the measurements of drag exerted on the flow by bushes at different flow depths. The analysis of velocity measurements allows depicting the fundamental characteristics of both the mean flow field and turbulence. The experimental data show that the contribution of form-induced stresses to the momentum balance cannot be neglected. The mean velocity profiles and the spatially averaged turbulent intensity profiles allow inferring that the vegetation density is a driving parameter for the development of a mixing layer at the canopy top in the case of submerged vegetation. Moreover, the net upward turbulent momentum flux, evaluated with the methodology proposed by Lu and Willmarth (1973), appears to be damped for increased vegetation density; this finding can rationally explain the reduction of the suspended sediment transport capacity typically observed in free surface flows over a vegetated bed.
16. **Lu et al. (2014)** elaborates the effects of rigid vegetation on the turbulence characteristics were experimentally studied in the interior water flume. An ADV was used to determine the three dimensional turbulent velocities in clear water flow without vegetation, sediment-laden flow without vegetation, sediment-laden flow with submerged vegetation and sediment-laden flow with non-submerged vegetation. By experimental and theoretical analysis, the effects of rigid vegetation on the distribution of averaged velocities, turbulence intensities and Reynolds stress were summarized. In sediment-laden flow with submerged vegetation, the averaged stream wise velocities above the top of vegetation fit well with the log distribution low. The three-dimensional turbulence intensities increase from the bottom until they reach the maximum at the top of the vegetation. The method to calculate the shear velocity with the maximum of the Reynolds stress is recommended. In sediment-laden flow with non-submerged vegetation, the turbulence problems cannot be explained by theory of bed shear flow. The average

velocities, turbulence intensities and Reynolds stress approximate uniformly distributed along vertical direction.

17. **Liu et al. (2008)** helps in better understanding of the role of vegetation in the transport of fluid and pollutants requires improved knowledge of the detailed flow structure within the vegetation. Instead of spatial averaging, this study uses discrete measurements at multiple locations within the canopy to develop velocity and turbulence intensity profiles and observe the changes in the flow characteristics as water travels through a vegetation array simulated by rigid dowels. Velocity data was collected with a one dimensional laser Doppler velocimeter under emergent and submerged flow conditions. The effects of dowel arrangement, density, and roughness were also examined. The results show that the velocity within the vegetation array is constant with depth and the velocity profile is logarithmic above it, however the boundaries are marked by inflection points. The strongest vortices and turbulence intensities can be found there, especially in the region immediately downstream of a dowel. These results support the idea that the flow in the region near the bed and at the top of the dowel array is very unstable leading to the formation of coherent structures and are areas of significant mass and momentum exchange.
18. **Okamoto et al. (2010)** talks about a lot of aquatic plants were observed in actual rivers, having a potential to improve water quality. A large-scale coherent vortex is generated near the vegetation edge, which dominate the momentum and scalar transport. Thus, estimating the flow resistance of vegetated flows is of great importance in river management. In such vegetated open-channel flows, both the geometry of the vegetation elements (shape, size, flexibility and vegetation density) and turbulence characteristics affect the hydrodynamic resistance significantly. However, any important relation between the vegetation motion and the flow resistance property is not yet established. Therefore, in the present study, we highlighted these important topics and measured the instantaneous velocity structure and coherent motion in open-channel flows with flexible vegetation by using PIV technique. As the results, the hydro-mechanic interaction between the flow and flexible plant motion was revealed.
19. **Poggi et al. (2009)** pointed that the past decade witnessed rapid developments in remote sensing methods that now permit an unprecedented description of the spatial variations in water levels (Hw), canopy height (hc), and leaf area density distribution (a) at large spatial scales. These developments are now renewing interest in effective resistance formulations for water flow within and above vegetated surfaces so that they can be

incorporated into simplified water routing models driven by such remote sensing products. The first generation of such water routing models linked the bulk velocity to gradients in Hw via a constant diffusion velocity that cannot be inferred from canopy properties (a and hc). The next generation of such hydrologic models must preserve the nonlinear relationship between the resistance value, canopy attributes (e.g., a and hc), and Hw without compromising model simplicity. Using a simplified scaling analysis on the depth-integrated mean momentum balance and a two-layer model for the bulk velocity, the Darcy-Weisbach friction factor (f) was shown to vary with three canonical length scales that can be either measured or possibly inferred from remote sensing products Hw, hc, and the adjustment length scale Lc = $(Cd\ a)^{-1}$, where Cd is the drag coefficient (of order unity). The scaling analysis proposed here reveals that these length scales can be combined in two dimensionless groups, Hw/hc and Lc/hc. The dependence of f on these two functional groups was then explored using a combination of first-order closure modeling and 130 experimental runs derived from a large number of flume experiments carried out for rigid and flexible vegetation. The results from the data and the model show a nonlinear decrease in f with increasing Hw/hc at a given Lc/hc and the nonlinear increase in f with decreasing Lc/hc. Furthermore, both model and data results did not exhibit any dependence on the bulk Reynolds number.

20. **Liu (2008)** shows better understanding of the role of vegetation in the transport of fluid and pollutants requires improved knowledge of the detailed flow structure within the vegetation. Instead of spatial averaging, this study uses discrete measurements at multiple locations within the canopy to develop velocity and turbulence intensity profiles and observe the changes in the flow characteristics as water travels through a vegetation array simulated by rigid dowels. Velocity data was collected with a one dimensional laser Doppler velocimetry (LDV) under emergent and submerged flow conditions. The effects of dowel arrangement, density, and roughness were also examined. The results show that the velocity within the vegetation array is constant with depth and the velocity profile is logarithmic above it, however the boundaries are marked by inflection points. The strongest vortices and turbulence intensities can be found there, especially in the region immediately downstream of a dowel. These results support the idea that the flow in the region near the bed and at the top of the dowel array is very unstable leading to the formation of coherent structures and are areas of significant mass and momentum exchange.

CHAPTER - 3

EXPERIMENTAL SETUP AND PROCEDURE

3.1. OVERVIEW

This thesis work improvises on the flume facility available in the Hydraulics Engineering Laboratory, Civil Engineering Department at the Delhi Technological University, Delhi, India. The main aim for conducting this experiment is to understand the concept of variation in velocity distribution. In order to understand the same, the section below describes a detailed summary of the geometric and hydraulic variables or can be said the parameters of vegetated open channel, experimental arrangements, measuring equipment. It also details about the procedure adopted in the experimentation process.

3.2. EXPERIMENTAL ARRANGEMENTS

3.2.1. GEOMETRY SETUP

The experiments used in the procedure consisted of a rectangular channel (simple rectangular channel) where, the cross section had the following dimensions 6.18m×0.3m×0.4m. The channel was covered by a plywood of 10 mm which was water resistant plywood. With a height of 10cm there were 6 mm diameter iron rods which were pushed deep into the plywood in a careen manner with 9cm spacing while the length of the channel is 3m.

Table. 1. Apparatus Required

S.No.	Measurement	Value
1.	Rectangular Channel	6.18m×0.3m×0.4m
2.	Plywood Height	10mm
3.	Length of vegetation	10cm
4.	Diameter of vegetation	6mm
5.	Spacing	9cm

The motor used in the purpose extracted water from an underground reservoir through a

Fig 4: Iron rod (Rigid vegetation)

Fig 5: wire (Flexible vegetation)

centrifugal pump of 10hp which stores water in an overhead tank. The pump is known to deliver water from the tank with a discharge of 0.047m/s into the flume. The water is directed for entry is through a notch (rectangular) pointing upstream which is constructed to compute the discharge (actual) in the channel placed in the laboratory.

A vertical gate was constructed at the section located at the upstream in combination with flow straighteners to decrease the velocity of approach adjacent to the notch section and also, decrease turbulence. Later, the downstream consists of a measuring flask in conjunction to a sump which completes the cycle of recirculation by providing feeds to the overhead tank (Fig.5). Also, in order to control the depth of flow, downstream end is equipped with another adjustable tail gate which is also used to maintain uniform flow. The flume also comprised of a movable gate so that each section of the channel can be easily accessed for measurements.

Some parameters to be considered:

Table. 2. List of parameters

S.No.	Parameter	value
1.	Aspect Ratio	1.33
2.	Slope (Channel Bed)	0.002375
3.	Discharge Variation	0.16

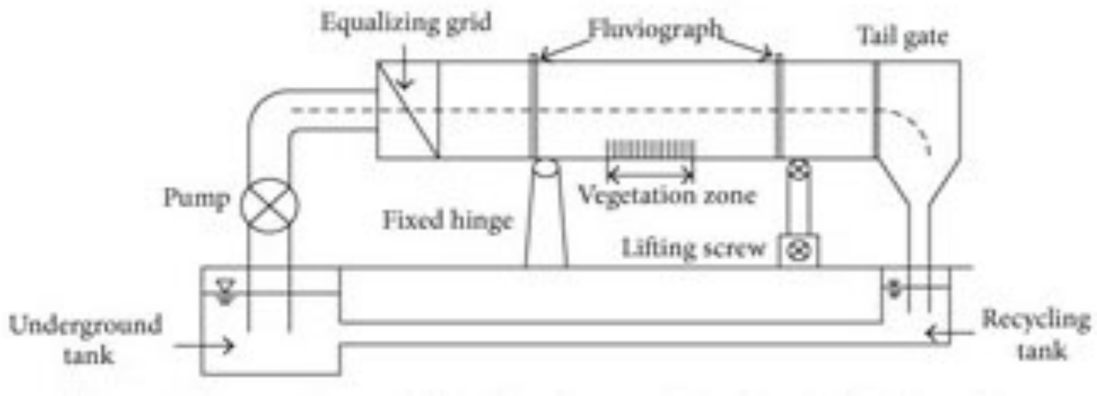

Fig.6. Plan view of experimental setup of the channel

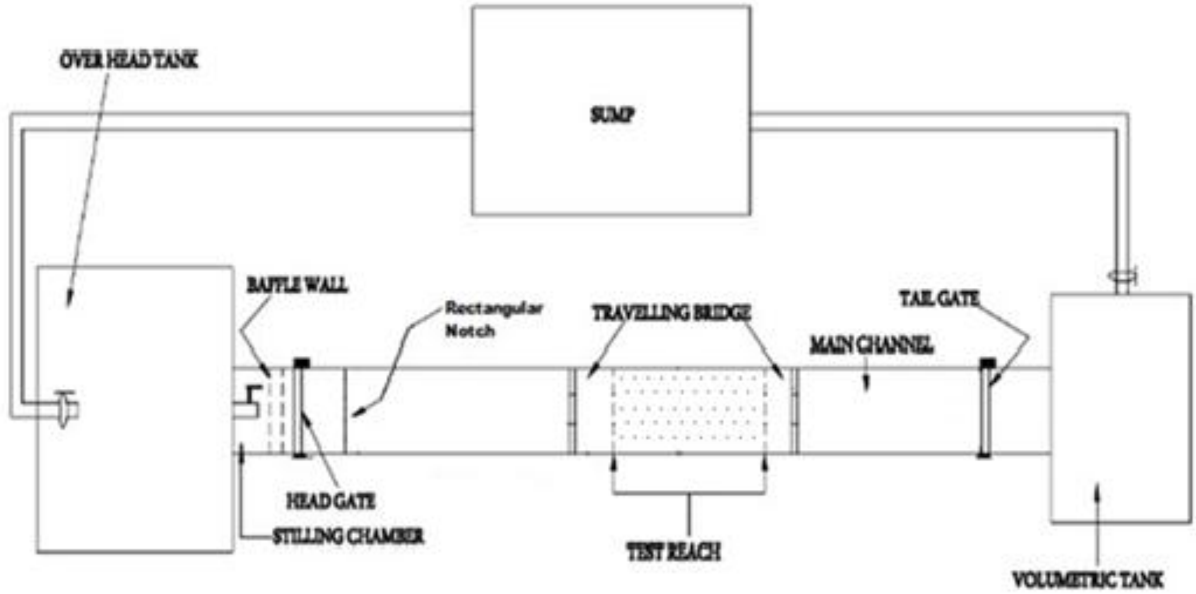

Fig. 7. Experimental setup

Fig. 8. Experimental setup in lab

Fig. 9. Full view of experimental setup

3.3. PROCEDURE

Water Current Meter was used to compute velocity during the experiments as it is competent to measure the same three dimensionally. The device is known to measure present value of velocity directly through velocity meter.

Fig. 10. Direct Velocity Meter

The task ahead is to choose a place for the water current meter to assess the desired section for velocity value computation. The selection of section should fulfil two main criterion:

1. Development Length: should be chosen in a manner where sectional velocity should meet and merge with the average channel velocity (V=Q/Bh). The sectional velocity is computed by considering three points in a section and calculating the average velocity value in that section.
2. Maximum cylinders are covered in the section in order to cover maximum points.

Pattern depicted below is for arranging vegetation in Careen Manner:

Fig.11. Careen Manner Vegetation

3.4. NUMERICAL SIMULATION

3.4.1. DESCRIPTION OF NUMERICAL MODEL PARAMETERS

In this study, for numerical simulation a computational fluid dynamics CFD model FLUENT is used. The various parameters used in this simulation is k-epsilon model, volume of fluid VOF and height of liquid HOL. The model uses transient flow for simulation of the vegetated channel. In addition to this a non iterative solution method SIMPLE is used. Because it will converge the flow faster which means the flow do not change with further iterations.

3.4.2. METHODOLOGY

In this numerical simulation process there are four steps involved:

(a) Geometry setup of the experimental channel

(b) Creating the mesh for the geometry

(c) Set up physics

(d) Post-processing.

3.4.2.1. STEP 1 - GEOMETRY SETUP

Step 1 being the geometry creation for the fluid flow area for which a uniform reference frame was adopted for coordinate axis where, X axis depict direction that is lateral indication width of bed channel and Y axis indicate vertical component depicting channel water depth. In addition to all this, Z axis depicts fluid flow direction which flows negative to the direction of z-axis. This simulation process involves both rigid and flexible vegetation.

Along with geometry setting up there were names given to various parts termed as names selection which was purposely initiated for conducting analysis and enhance boundary condition application.

The names selection has all these six parts:

1. Inlet
2. Outlet
3. Cylinders
4. Sidewalls

5. Bottom surface

6. Top

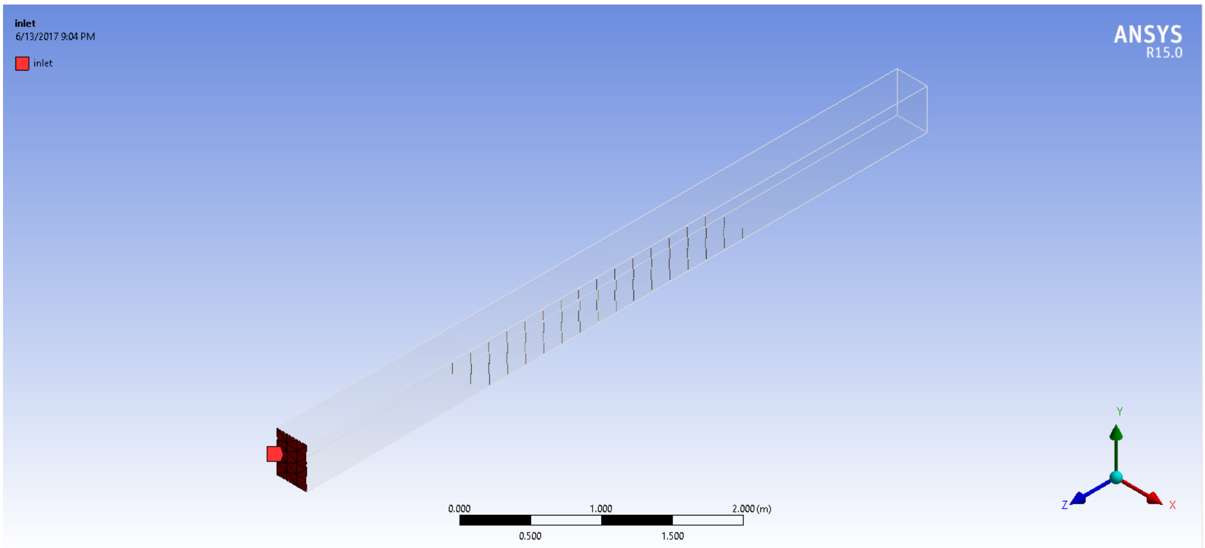

Fig 12: Inlet

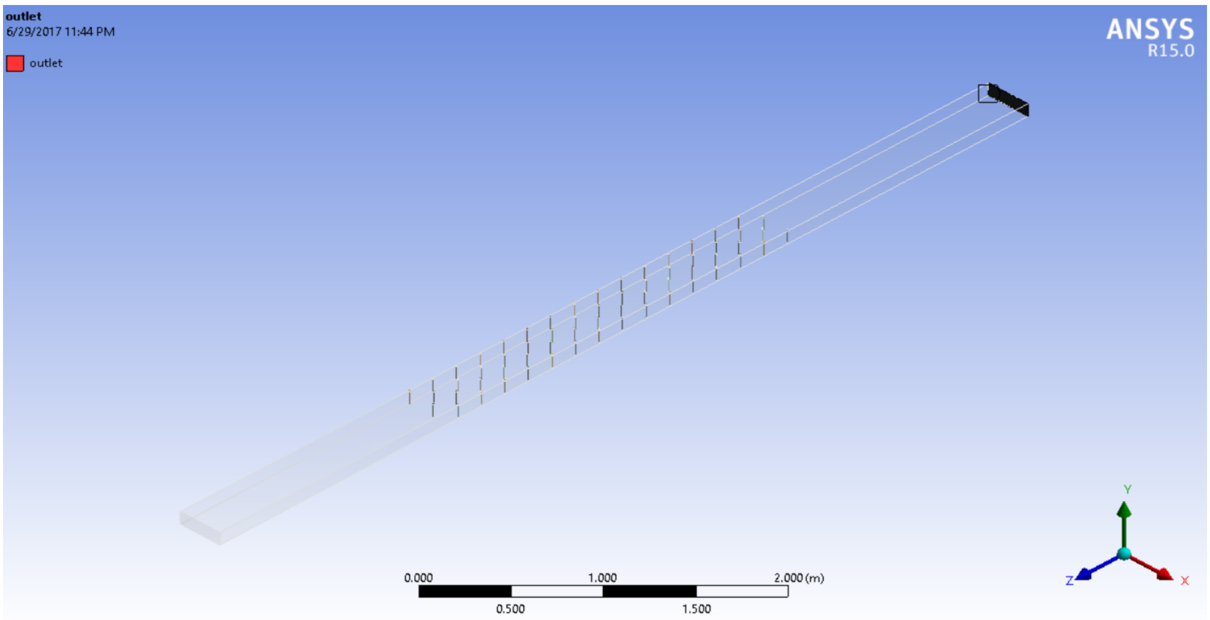

Fig 13: Outlet

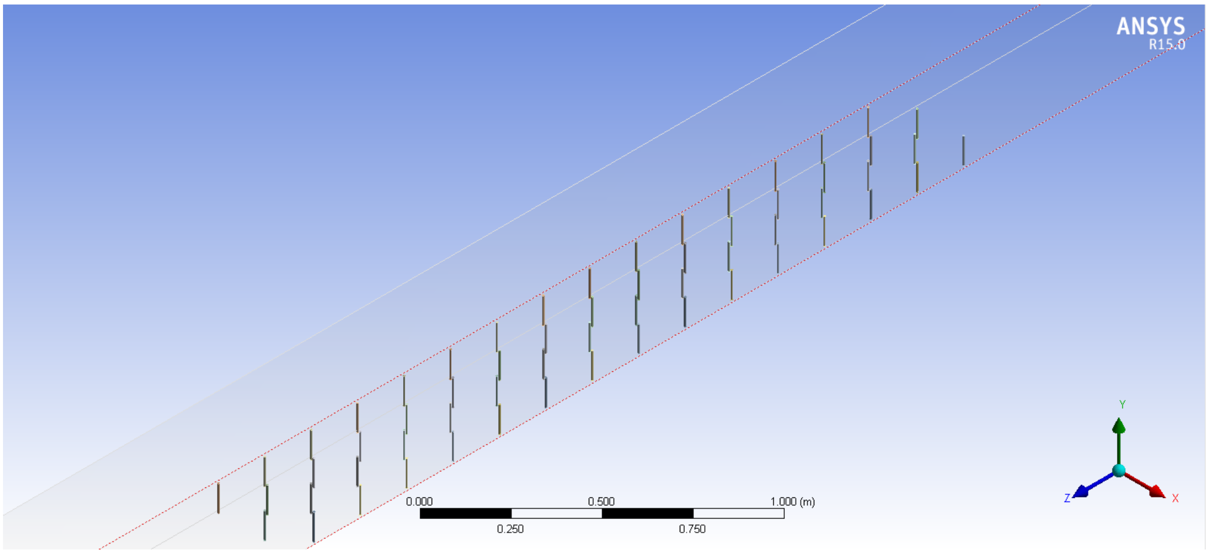

Fig 14: Cylinder

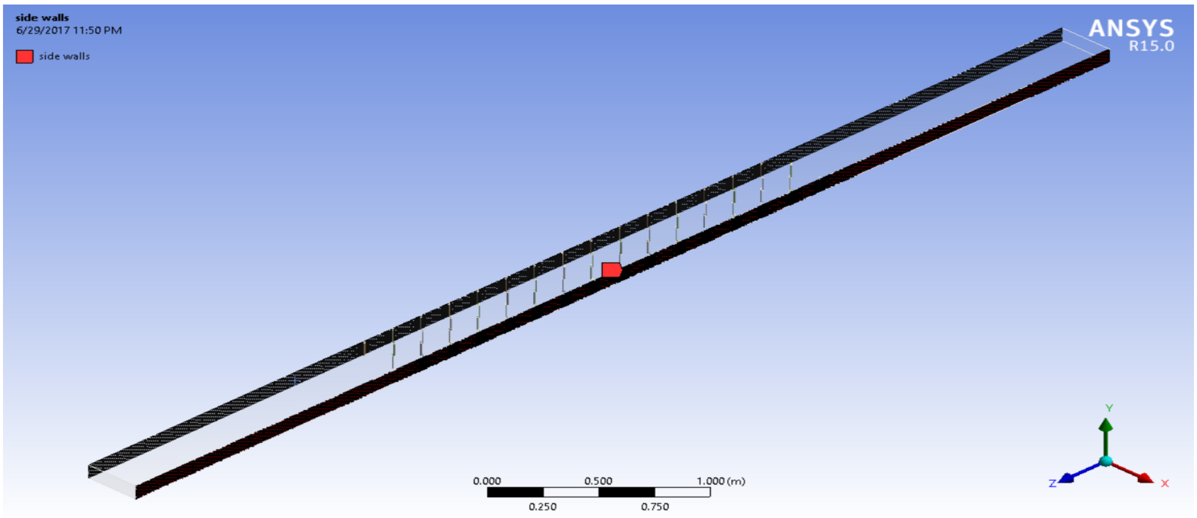

Fig 15: Side Walls

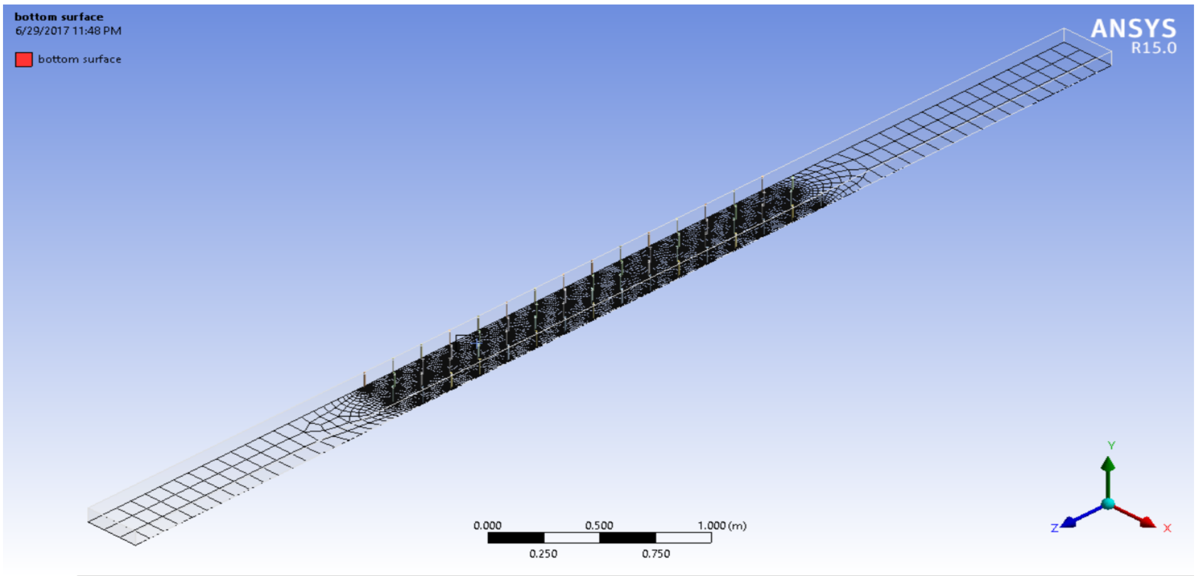

Fig 16: Bottom Surface

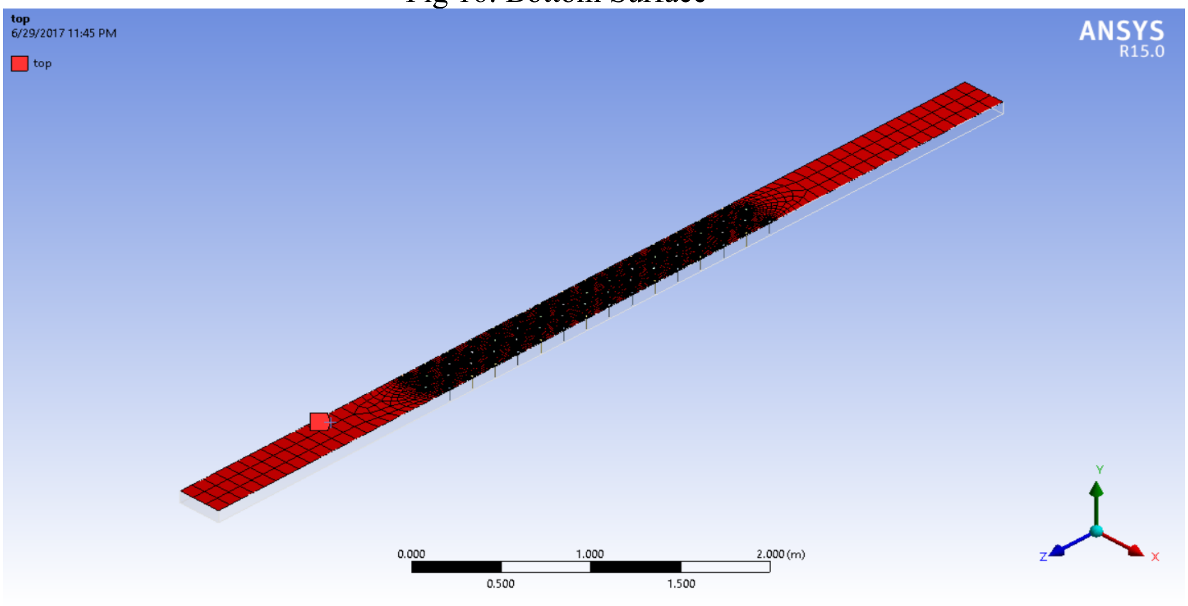

Fig 17: Top

3.4.2.2. STEP 2 - MESH GENERATION

The most essential step in the process is the following step which involves geometry meshing. In this step meshing of geometry takes place which is defined as categorizing geometry into cells in which all the calculus part will take place. The process also breaks the chain in various number of nodes. There are three different ways to discretize the fluid domain i.e. Finite element, Finite Volume and Finite Difference Method. The finite volume method is used for discretization dividing the mentioned domain into several volumes solving the discretization equation in the centre of the cell with some specified variables whereas the value for velocity by pointing at the middle and summing the whole volume.

Following step is termed as meshing dense where care should be taken so that it doesn't get too dense or too light. This is done as if meshing is dense then it will result into more space for memory and much extra time whereas in case of light meshing, it is responsible for varied results not exactly like the experimental ones. Thus, essential prevention must be adopted in case of meshing and thus, to do so meshing is highly dense near cylinders adjacent to walls as compared to the dense criterion for other parts. This step is necessary for converging to take place during the process. The meshing of the vegetated channel is shown in the Figure.

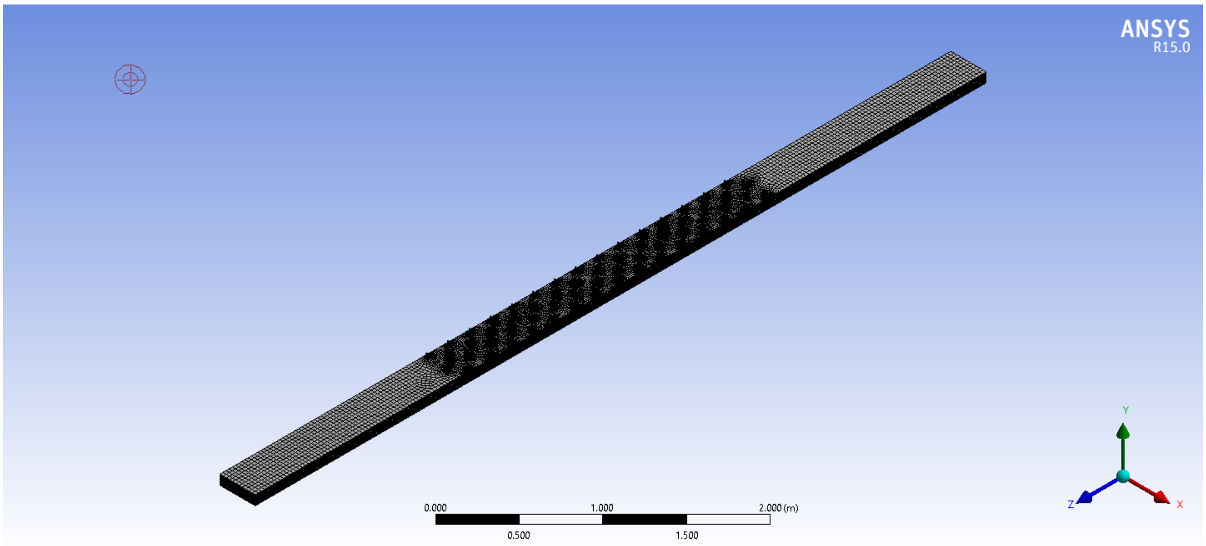

Fig 18: Meshing

3.4.2.3. STEP 3 - SETUP PHYSICS

After proper meshing comes the step where calculations and numerical simulation plays an important role filled with several basic numerous processes. The several processes involve various models used for analysis, the initial and boundary conditions, the number of Eulerian phases, the properties of the materials.

The model used in this is K-epsilon RNG (Re-Normalisation Group).

<u>RNG k-epsilon model:</u>

The RNG model Re-Normalisation Group (RNG) renormalizes the Navier-Stokes equations, to account for the effects of smaller scales of motion. There are a number of ways to write the transport equations for k and ϵ, a simple interpretation where bouyancy is neglected is

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left[\left(\mu + \frac{\mu_t}{\sigma_k}\right)\frac{\partial k}{\partial x_j}\right] + P_k - \rho \in \qquad (1)$$

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

Where,

$$C^*{}_{2\in} = C_{2\in} + \frac{C_\mu \eta^3(1-\frac{\eta}{\eta_0})}{1+\beta\eta^3} \tag{3}$$

$$\eta = Sk/\epsilon \tag{4}$$

$$S = (2S_{ij}S_{ij})^{1/2} \tag{5}$$

Some of them are mentioned below along with usually used values in the k-epsilon equation: It is interesting to note that the values of all of the constants (except β) are derived explicitly in the RNG procedure. They are given below with the commonly used values in the standard k-epsilon equation in brackets for comparison

$C_\mu = 0.0845(0.09)$

$\sigma_k = 0.7194(1.0)$

$\sigma_\epsilon = 0.7194(1.30)$

$C_{\epsilon 1} = 1.42(1.44)$

$C_{\in 2} = 1.68(1.92)$

$\eta_0 = 4.38$

Boundary condition set up plays an essential part in this step. If not done properly the results can fall below or beyond the estimation. In order to complete step, transient flow is taken. Here, gravity effect along with slope of channel are executed through a settled vector for gravity where the angle θ represents the angle between the channel bed and horizontal. Also, the mentioned factor of gravity is resolved in x, y and z components as:

$(0, -\rho g\cos\theta, \rho g\sin\theta)$

Where,

θ = angle between bed surface to horizontal axis

tan θ= channel slope.

Non-Slip Walls are considered in this part including side and bottom walls. Such a condition is the most frequently used condition which states that it will be implemented at the walls taking into account that fluid adjacent to the wall is considered as the wall velocity pertaining to zero.

Also, for a surface that is free from the top symmetry boundary condition is utilised stating that the stress (shear stress) at the considering wall is zero. Also, such a condition talks about stream wise and lateral velocities of the fluid near the wall are not deaccelerated due to friction in wall unlike the no-slip condition. This condition follows a strict principle that across the boundary, there is no occurrence of scalar flux.

3.4.2.4. STEP 4 - POST-PROCESSING

This is the last part of the process. The process involves displaying of the results after the whole process, after all involved calculations where the results involves:

1. Velocity Streamlines

2. x-y plots

   (a) vertical velocity profiles

CHAPTER – 4

RESULTS AND DISCUSSION

The experimental results of the velocity profiles and relative depth variation are presented in this chapter. Analysis is done at three velocities.

Section taken is shown in the figure below:

Fig. 19. Sectional View of the Plume where experiment was conducted

The section is taken 1.29m away from the inlet for unsubmerged depth and vegetation length is about 3m.

Total 3 sections are taken here.

1st section is at 1.29m from inlet.

2nd section is at 2.79m from inlet.

3rd section is at 4.29m from inlet.

The depth and velocity is first computed experimentally and the same is then verified by the software. The section as formed in the software can be seen below:

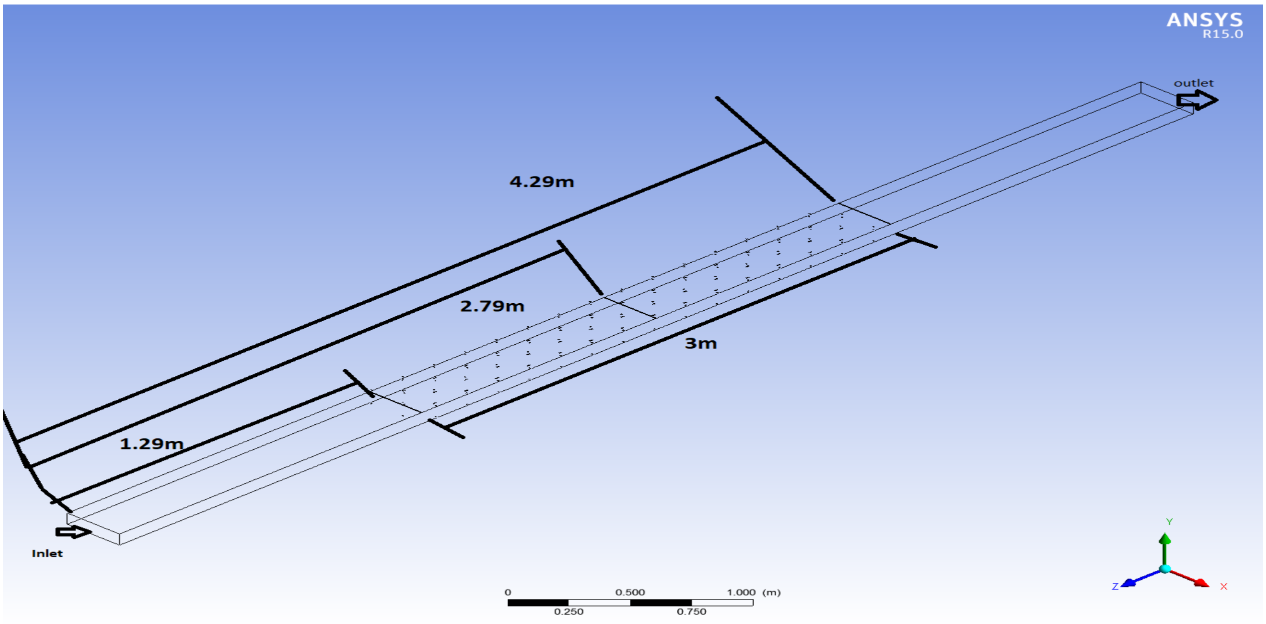

Fig. 20. Sectional View of Plume in ANSYS (Software)

The results of the same can be shown in the graphs below for flexible and rigid vegetation at three velocities 0.2m/s, 0.3m/s and 0.4m/s where it was established that the velocity for all the three sections were close enough for experiment and software.

Table 3: velocity obtained from Experiment and software in Rigid Vegetation

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) From ANSYS (m/sec)	Velocity(v_2) From software (m/sec)
Velocity=0.4 m/s	1.29m	0.42554	0.40
	2.79m	0.462281	0.431
	4.29m	0.42647	0.421
Velocity=0.3 m/s	1.29m	0.320014	0.320
	2.79m	0.349095	0.335
	4.29m	0.323684	0.321
Velocity=0.2 m/s	1.29m	0.216898	0.214
	2.79m	0.236444	0.225
	4.29m	0.230621	0.230

Table 4: velocity obtained from Experiment and software in Flexible Vegetation

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) From ANSYS (m/sec)	Velocity(v_2) From software (m/sec)
Velocity=0.4 m/s	1.29m	0.423236	0.421
	2.79m	0.46271	0.462
	4.29m	0.426455	0.421
Velocity=0.3 m/s	1.29m	0.314565	0.312
	2.79m	0.339876	0.320
	4.29m	0.323684	0.321
Velocity=0.2 m/s	1.29m	0.215858	0.214
	2.79m	0.235582	0.231
	4.29m	0.220691	0.225

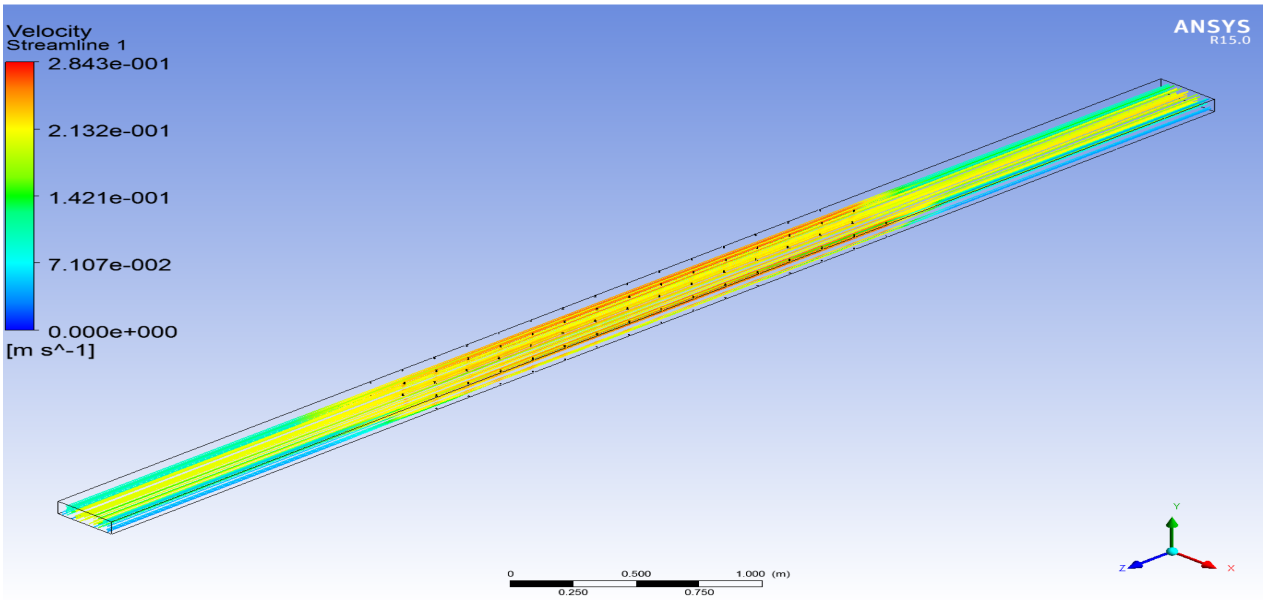

Fig 21: Streamline at v=0.2m/sec in rigid vegetation

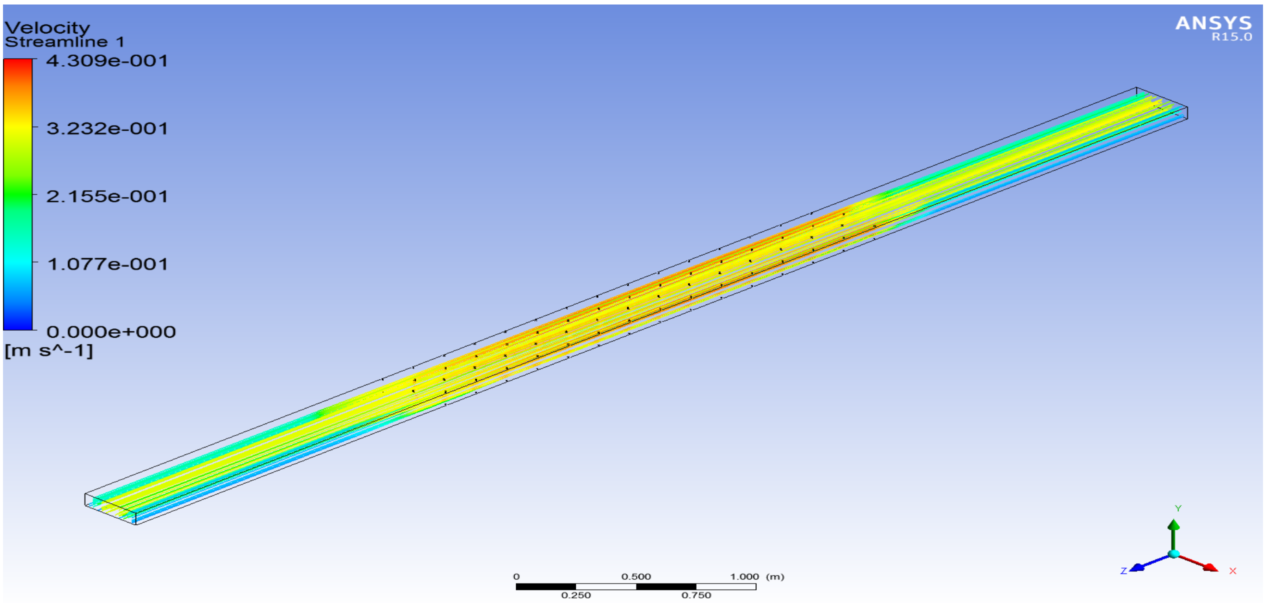

Fig 22: Streamline at v=0.3m/sec in rigid vegetation

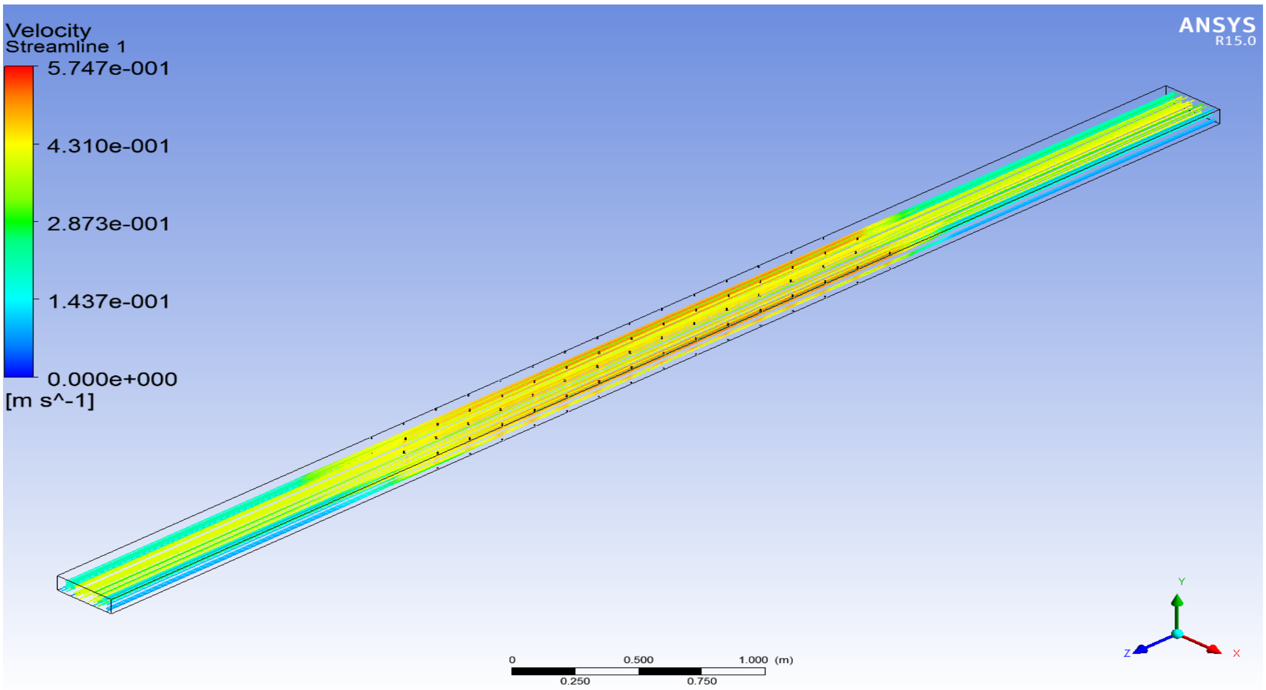

Fig 23: Streamline at v=0.4m/sec in rigid vegetation

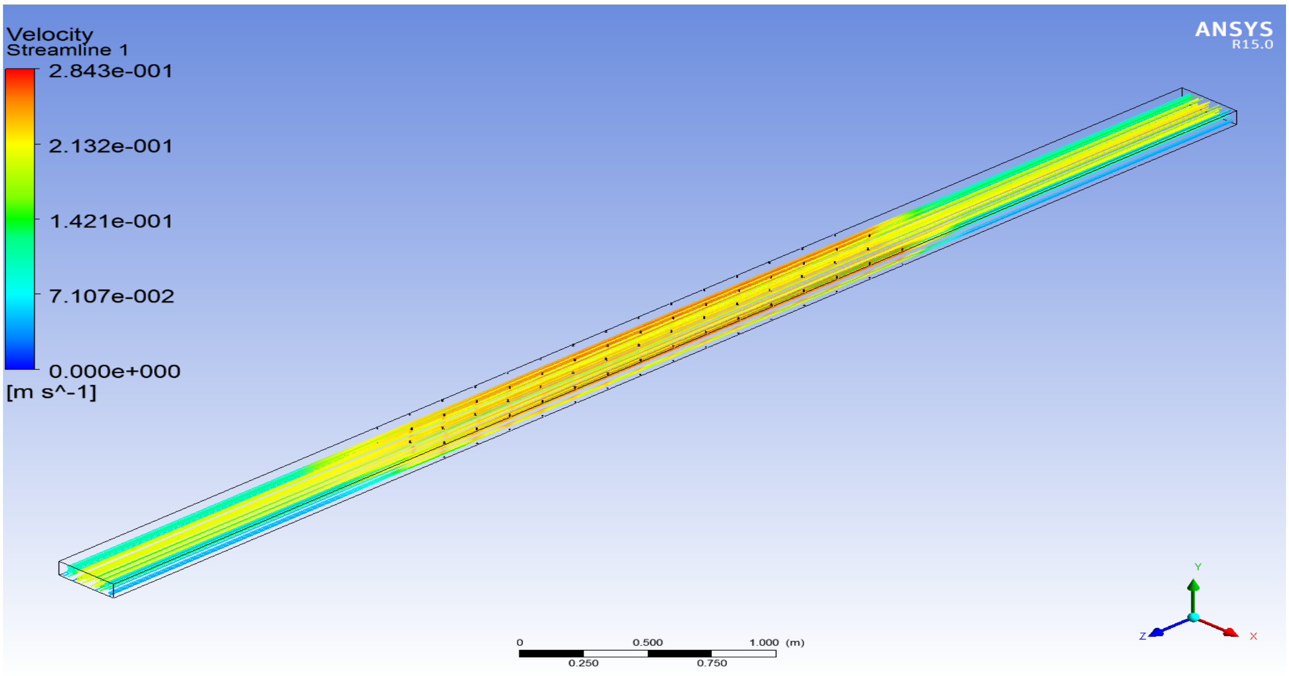

Fig 24: Streamline at v=0.2m/sec in Flexible vegetation

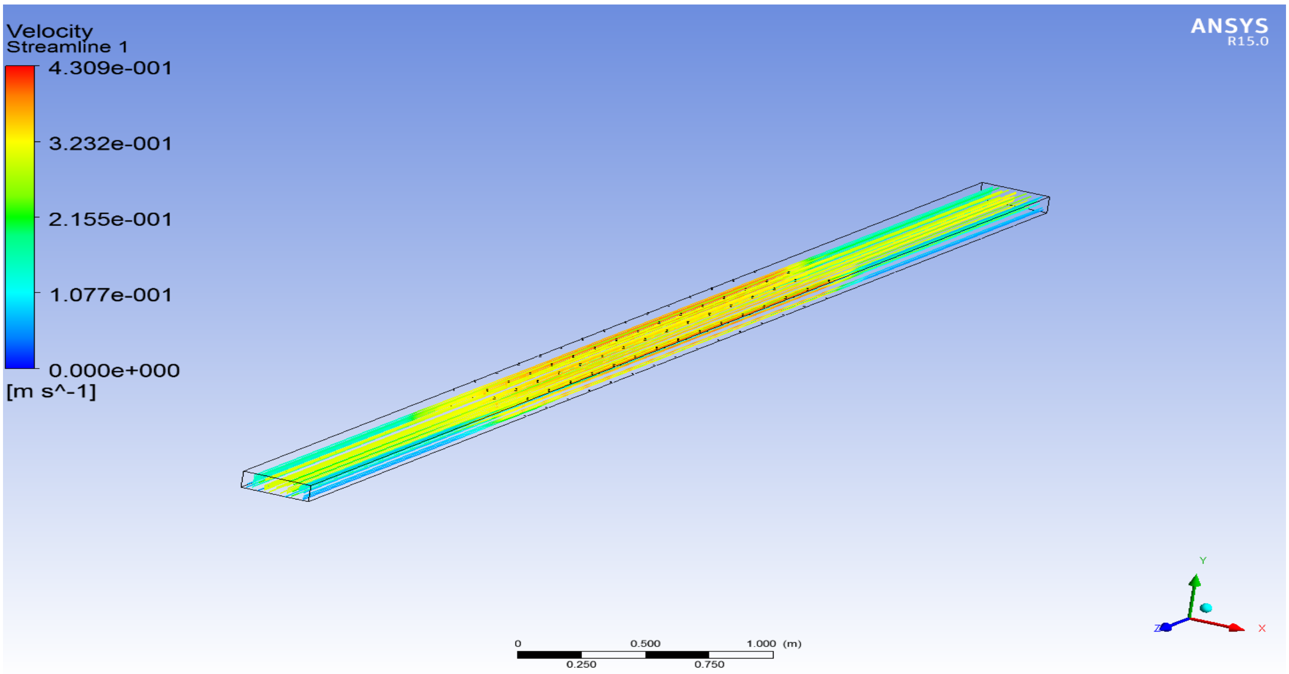

Fig 25: Streamline at v=0.3m/sec in Flexible vegetation

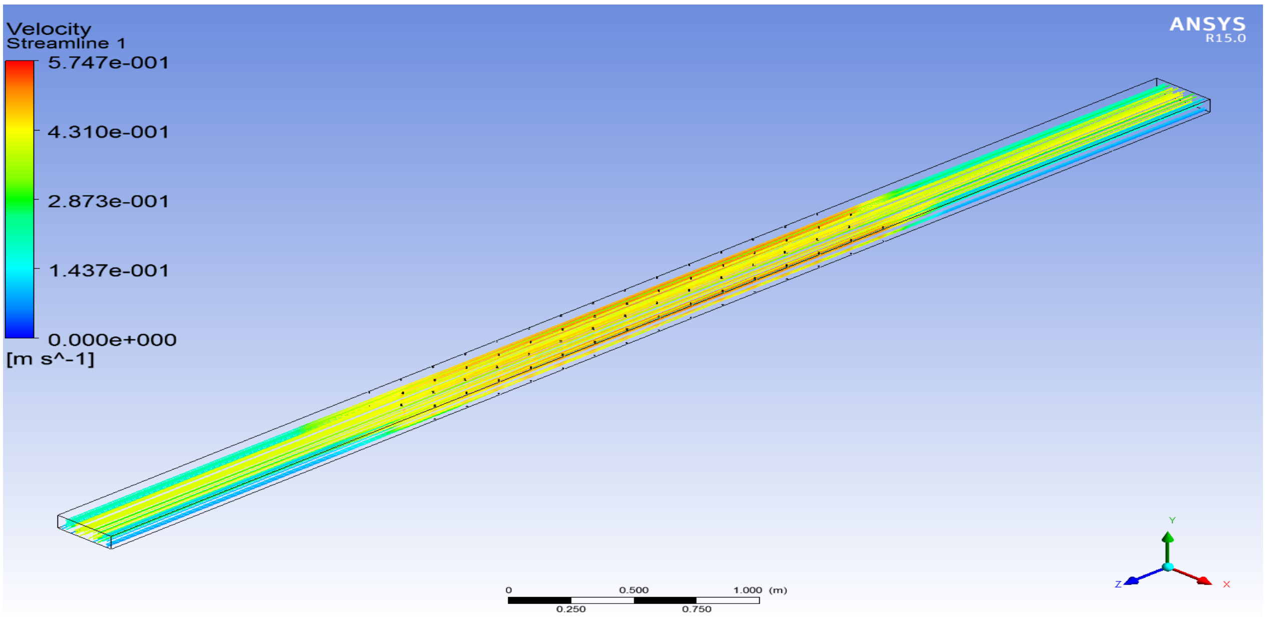

Fig 26: Streamline at v=0.4m/sec in Flexible vegetation

Comparison of results obtained for Rigid Vegetation

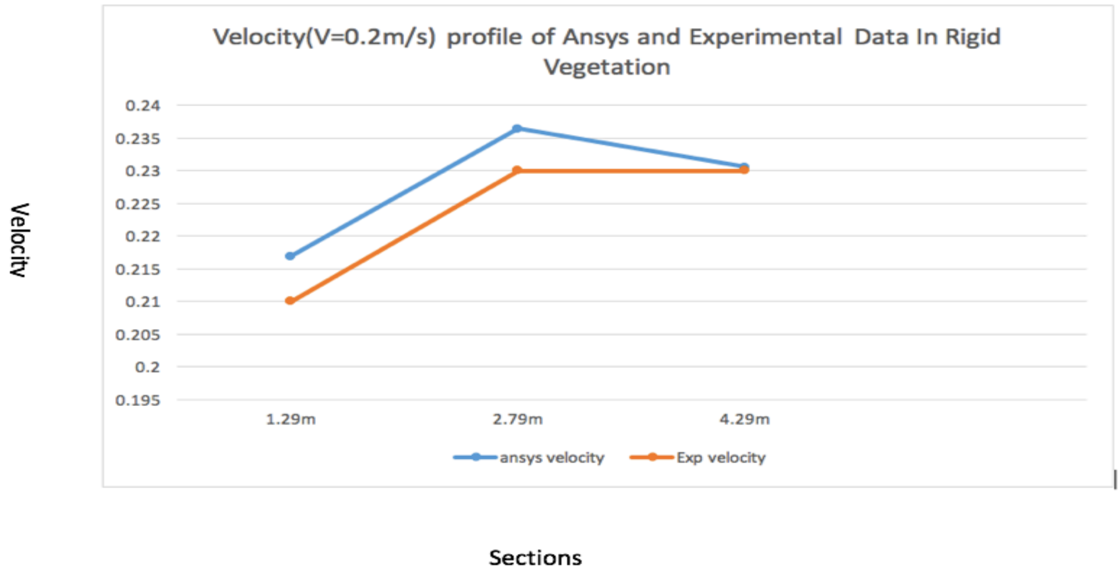

Fig.27. Comparison at 0.2 m/s

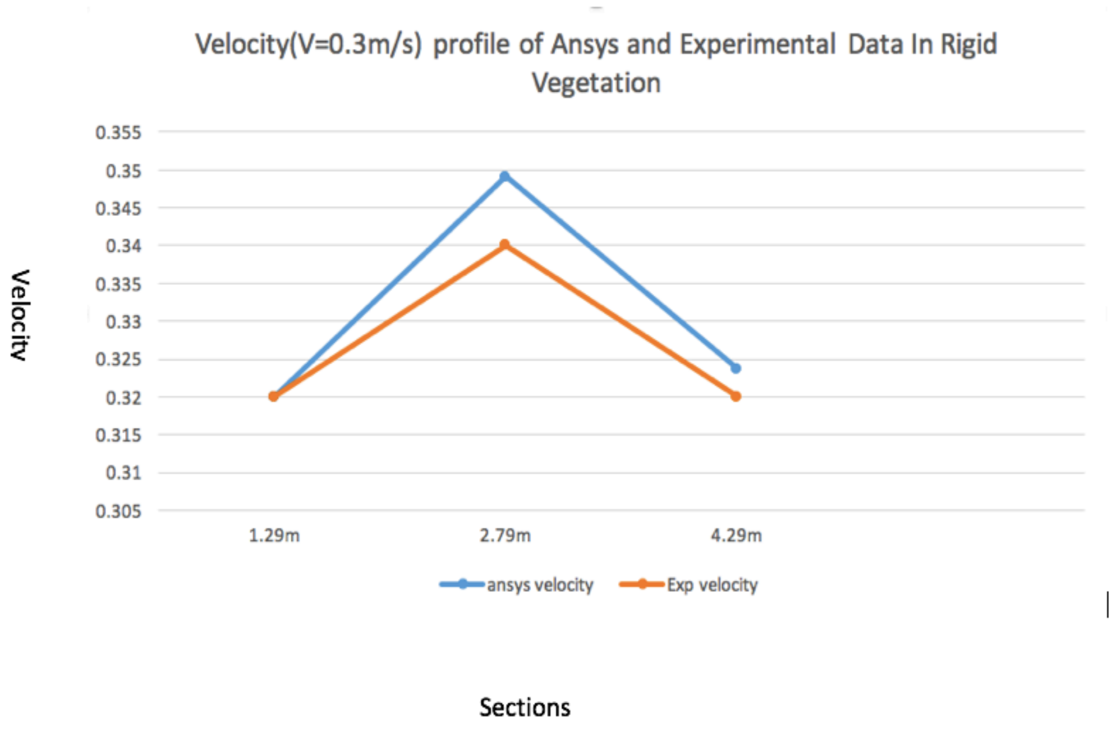

Fig.28. Comparison at 0.3 m/s

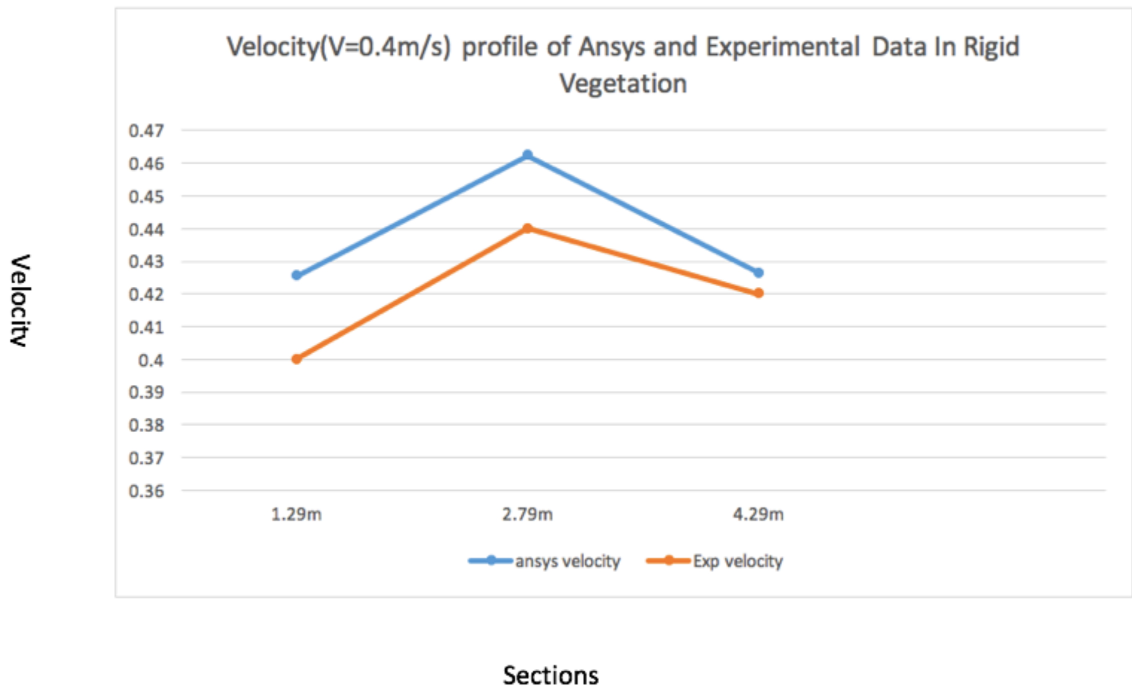

Fig.29. Comparison at 0.4 m/s

Comparison of results obtained for Flexible Vegetation:

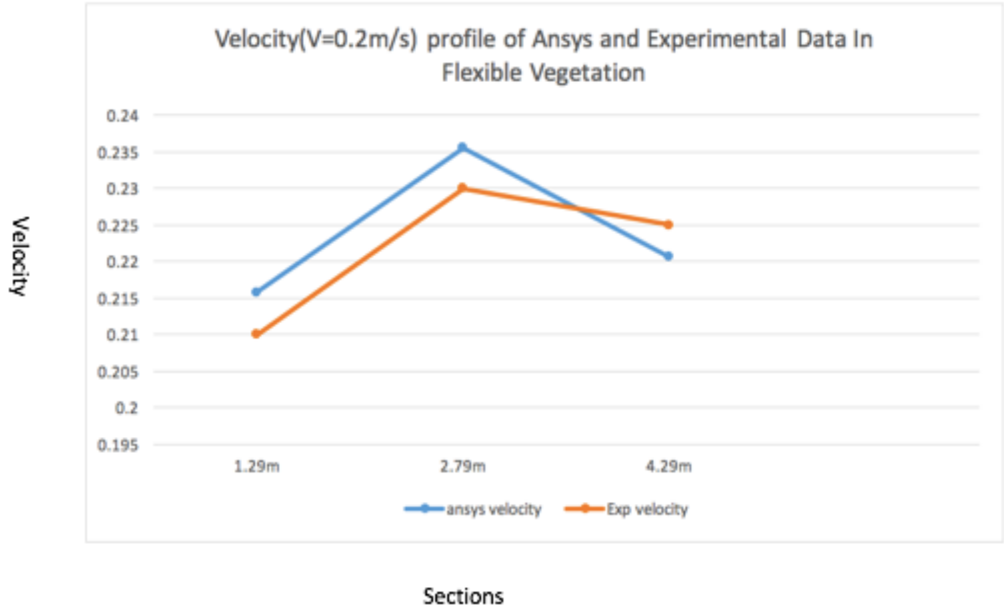

Fig.30. Comparison at 0.2 m/s

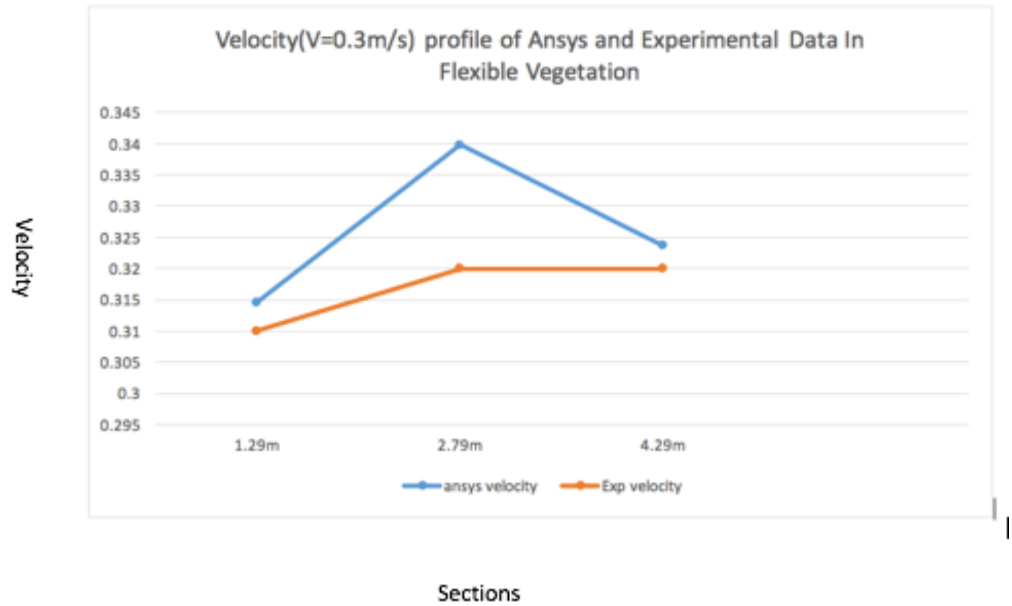

Fig.31. Comparison at 0.3 m/s

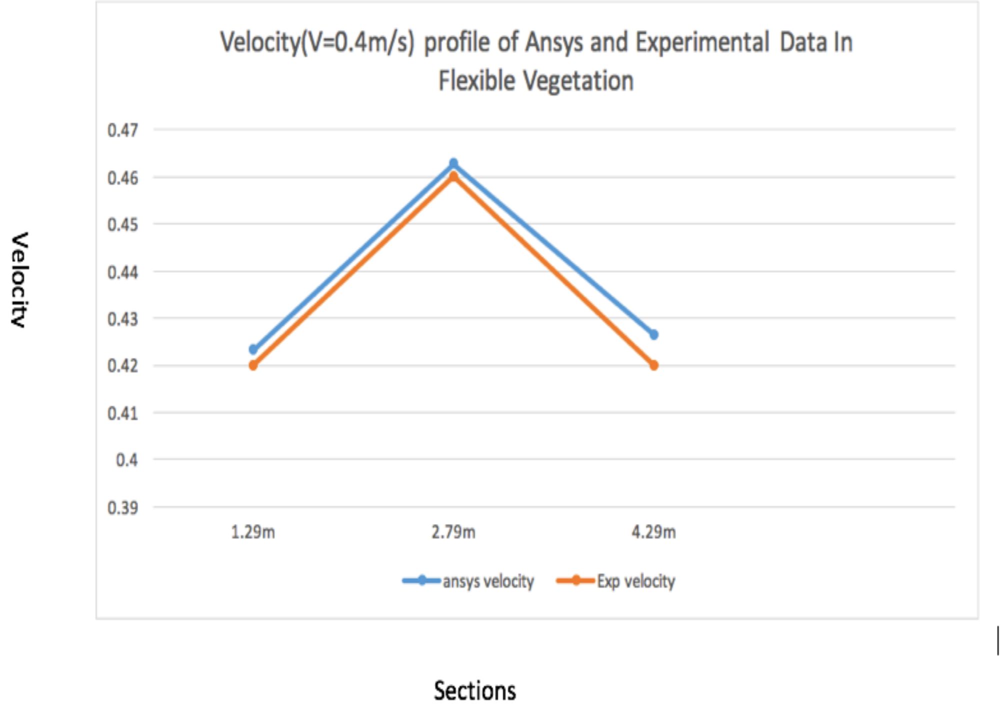

Fig.32. Comparison at 0.4 m/s

After the depth and velocity was verified experimentally and by software, five other parameters were computed in order to differentiate between the results obtained from rigid and flexible vegetation, which were:

- Reynold's Number (R_e)
- Froude's Number (F_r)
- Manning's Coefficient (n)
- Coefficient of Discharge (C_d)
- Head Loss (h_L)

The following formulae have been used to compute the different parameters for both rigid and flexible:

For calculating y_2

$$y_2 = \frac{{v_1}^2 - {v_2}^2}{2g} + y_1 \qquad (1)$$

y_2=Relative Depth

y_1=Initial Depth

g=Acceleration due to gravity

v_1=Initial velocity

v_2=Relative velocity at section

For calculating Reynold's Number:

$$R_e = \frac{\mu * L}{\nu} \tag{2}$$

Where,

R_e = Reynold's Number

$\nu = kinematic\ viscosity$

μ = Velocity

L= Characteristic Length

$$L = \frac{Wetted\ Area}{Wetted\ Perimeter} \tag{3}$$

$$L = \frac{y_2 * b}{(2 * y_2) + b} \tag{4}$$

For calculating Froude's Number

$$F_r = \frac{\mu}{\sqrt{gL}} \tag{5}$$

For Manning's Equation:

$$V = \frac{1}{n} R^{2/3} S^{1/3} \tag{6}$$

Where,

S = Slope with value 0.002375

R = Wetted Area / Wetted Perimeter

$$R = \frac{y_2 * b}{(2 * y_2) + b} \tag{7}$$

For calculation Head Loss,

$$h_L = E_1 - E_2 \tag{8}$$

$$h_L = \frac{{v_1}^2}{2g} + y_1 - (\frac{{v_2}^2}{2g} + y_2) \tag{9}$$

For calculating Coefficient of Discharge

$$C_d = \frac{Q_{actual}}{Q_{theoritical}} \tag{10}$$

Where,

$$Q_{theoritical} = \frac{a_1 a_2 \sqrt{2gh_1}}{\sqrt{a_1{}^2 - a_2{}^2}} \tag{11}$$

Where,

$a_1 = 0.1016$

$a_2 = 0.0762$

$$Q_{actual} = v_2 * A \tag{12}$$

The above formulae have been used to differentiate between rigid and flexible vegetation, the results obtained from the experimental work described how the above parameters differ for rigid and flexible vegetation where the value for R_e escalated up to 5955 for flexible which means that the flow is turbulent at maximum discharge velocity i.e. at 0.4 m/s. Similarly, the F_r was seen falling into the range of 0.1 to 1, again being the highest for flexible. C_d depicts the irrecoverable losses in an equipment which was seen quite low here, as low as 0.0189 and the same is the case for the Manning's Coefficient which gave low values explaining that the roughness offered to the flow was less.

The results for **rigid vegetation** are as follows:

Table 5. Reynold's Number at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Reynolds Number (Re)
Velocity=0.4 m/s	1.29m	0.42554	0.908925367	5478.914465
	2.79m	0.462281	0.907262807	5950.417743
	4.29m	0.42647	0.908884982	5490.853844
Velocity=0.3 m/s	1.29m	0.320014	0.909367535	4120.529458
	2.79m	0.349095	0.908375774	4494.284288
	4.29m	0.323684	0.909247129	4167.706
Velocity=0.2 m/s	1.29m	0.216898	0.909640941	2792.917297
	2.79m	0.236444	0.909189309	3044.390013
	4.29m	0.230621	0.909327928	2969.478722

Table 6. Froude's Number at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Froude's Number (Fr)
Velocity=0.4 m/s	1.29m	0.42554	0.908925367	0.37864203
	2.79m	0.462281	0.907262807	0.411387256
	4.29m	0.42647	0.908884982	0.379470731
Velocity=0.3 m/s	1.29m	0.320014	0.909367535	0.284736047
	2.79m	0.349095	0.908375774	0.310635202
	4.29m	0.323684	0.909247129	0.288004171
Velocity=0.2 m/s	1.29m	0.216898	0.909640941	0.192983323
	2.79m	0.236444	0.909189309	0.210381622
	4.29m	0.230621	0.909327928	0.205198255

Table 7. Manning's Coefficient (n) at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Manning's Coefficient (n)
Velocity=0.4 m/s	1.29m	0.42554	0.908925367	0.079943576
	2.79m	0.462281	0.907262807	0.073577117
	4.29m	0.42647	0.908884982	0.079768909
Velocity=0.3 m/s	1.29m	0.320014	0.909367535	0.106310197
	2.79m	0.349095	0.908375774	0.097444093
	4.29m	0.323684	0.909247129	0.105103515
Velocity=0.2 m/s	1.29m	0.216898	0.909640941	0.156855834
	2.79m	0.236444	0.909189309	0.143882365
	4.29m	0.230621	0.909327928	0.147517405

Table 8. Coefficient of Discharge at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Discharge Coefficient (Cd)
Velocity=0.4 m/s	1.29m	0.42554	0.908925367	0.01744014
	2.79m	0.462281	0.907262807	0.018911262
	4.29m	0.42647	0.908884982	0.017477478
Velocity=0.3 m/s	1.29m	0.320014	0.909367535	0.013969106
	2.79m	0.349095	0.908375774	0.015221917
	4.29m	0.323684	0.909247129	0.014127436
Velocity=0.2 m/s	1.29m	0.216898	0.909640941	0.013863802
	2.79m	0.236444	0.909189309	0.01510565
	4.29m	0.230621	0.909327928	0.014735883

Table 9. Head Loss at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Head Loss (H_L)
Velocity=0.4 m/s	1.29m	0.42554	0.908925367	0.092010288
	2.79m	0.462281	0.907262807	0.095028793
	4.29m	0.42647	0.908884982	0.092083001
Velocity=0.3 m/s	1.29m	0.320014	0.909367535	0.087636997
	2.79m	0.349095	0.908375774	0.089440199
	4.29m	0.323684	0.909247129	0.087857049
Velocity=0.2 m/s	1.29m	0.216898	0.909640941	0.084591987
	2.79m	0.236444	0.909189309	0.085414098
	4.29m	0.230621	0.909327928	0.085161324

The results for **flexible vegetation** are as follows:

Table 10: Reynold's Number at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Reynolds Number (Re)
Velocity=0.4 m/s	1.29m	0.423236	0.90902504	5449.334633
	2.79m	0.46271	0.907242582	5955.920934
	4.29m	0.426455	0.908885634	5490.661275
Velocity=0.3 m/s	1.29m	0.314565	0.909543775	4050.478767
	2.79m	0.339876	0.908699506	4375.818892
	4.29m	0.323684	0.909247129	4167.706567
Velocity=0.2 m/s	1.29m	0.215858	0.90966388	2779.535514
	2.79m	0.235582	0.909210047	3033.300929
	4.29m	0.220691	0.909556345	2841.720975

Table 11: Froude's Number at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Froude's Number (Fr)
Velocity=0.4 m/s	1.29m	0.423236	0.909025 04	0.376589025
	2.79m	0.46271	0.907242582	0.411769678
	4.29m	0.426455	0.908885 634	0.379457365
Velocity=0.3 m/s	1.29m	0.314565	0.909543 775	0.279883899
	2.79m	0.339876	0.908699 506	0.302424224
	4.29m	0.323684	0.909247129	0.288004171
Velocity=0.2 m/s	1.29m	0.215858	0.909663 88	0.192057648
	2.79m	0.235582	0.909210047	0.209614298
	4.29m	0.220691	0.909556 345	0.196359408

Table 12. Manning's Coefficient at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Manning's Coefficient (n)
Velocity=0.4 m/s	1.29m	0.423236	0.90902504	0.080379603
	2.79m	0.46271	0.907242582	0.073508746
	4.29m	0.426455	0.908885634	0.07977172
Velocity=0.3 m/s	1.29m	0.314565	0.909543775	0.108153716
	2.79m	0.339876	0.908699506	0.100090594
	4.29m	0.323684	0.909247129	0.105103515
Velocity=0.2 m/s	1.29m	0.215858	0.90966388	0.157611938
	2.79m	0.235582	0.909210047	0.144409145
	4.29m	0.220691	0.909556345	0.154158611

Table 13. Discharge Coefficient at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Discharge Coefficient (Cd)
Velocity=0.4 m/s	1.29m	0.423236	0.90902504	5449.334633
	2.79m	0.46271	0.907242582	5955.920934
	4.29m	0.426455	0.908885634	5490.661275
Velocity=0.3 m/s	1.29m	0.314565	0.909543775	0.01373391
	2.79m	0.339876	0.908699506	0.014825214
	4.29m	0.323684	0.909247129	0.014127436
Velocity=0.2 m/s	1.29m	0.215858	0.90966388	2779.535514
	2.79m	0.235582	0.909210047	3033.300929
	4.29m	0.220691	0.909556345	2841.720975

Table 14. Head Loss at the three velocities for every section

Velocity(v_1) (m/sec)	Section (m)	Velocity(v_2) (m/sec)	Depth(y2) (m)	Headloss (H_L)
Velocity=0.4 m/s	1.29m	0.423236	0.909025 04	0.0918284 93
	2.79m	0.46271	0.907242582	0.095065083
	4.29m	0.426455	0.908885 634	0.092081183
Velocity=0.3 m/s	1.29m	0.314565	0.909543 775	0.0873168 68
	2.79m	0.339876	0.908699 506	0.088851466
	4.29m	0.323684	0.909247129	0.087857049
Velocity=0.2 m/s	1.29m	0.215858	0.909663 88	0.0845501 43
	2.79m	0.235582	0.909210047	0.085375912
	4.29m	0.220691	0.909556 345	0.084746619

The results for both rigid and flexible can be analyzed via the following graphs Results obtained for Rigid Vegetation

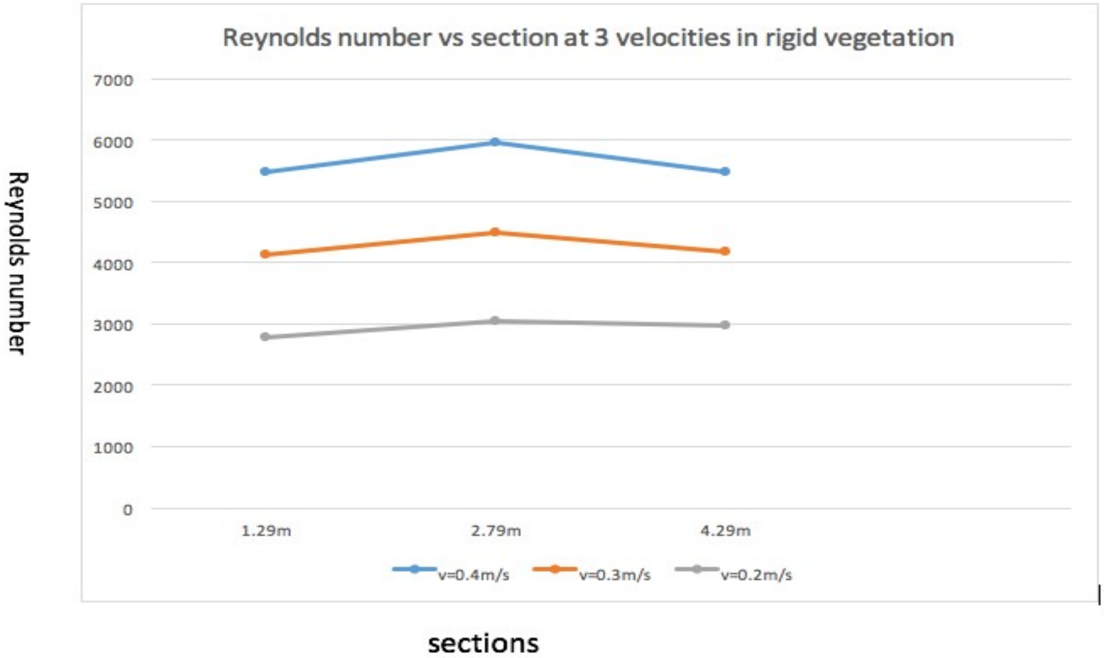

Fig. 33. Reynold's Number for Rigid Vegetation

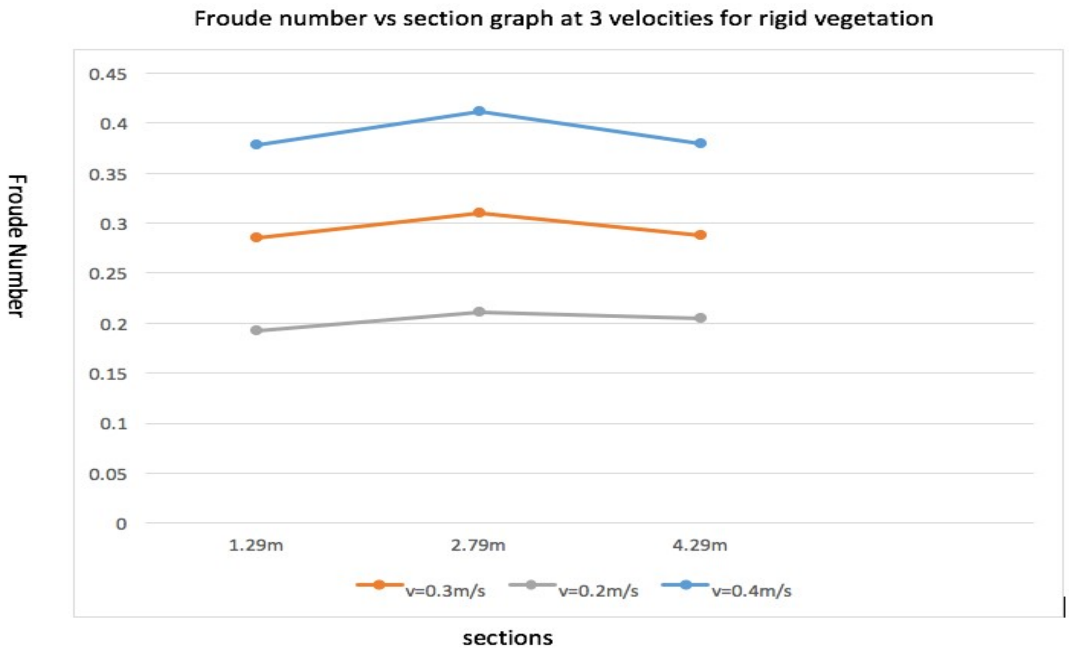

Fig. 34. Froude's Number for Rigid Vegetation

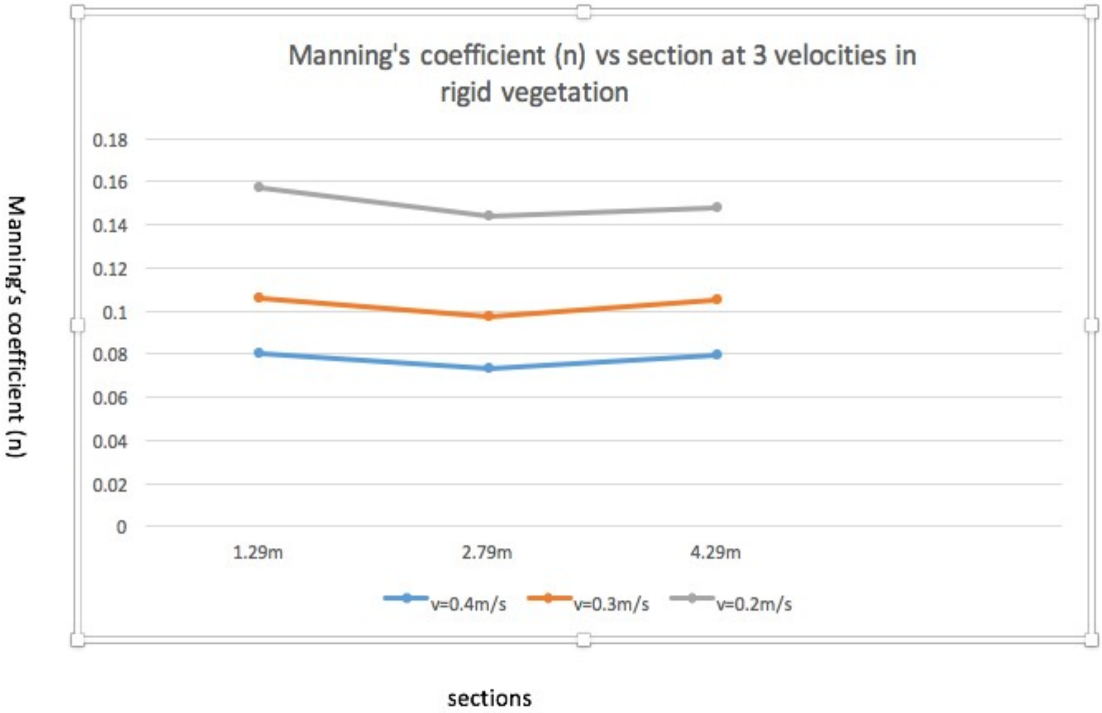

Fig. 35. Manning's Coefficient for Rigid Vegetation

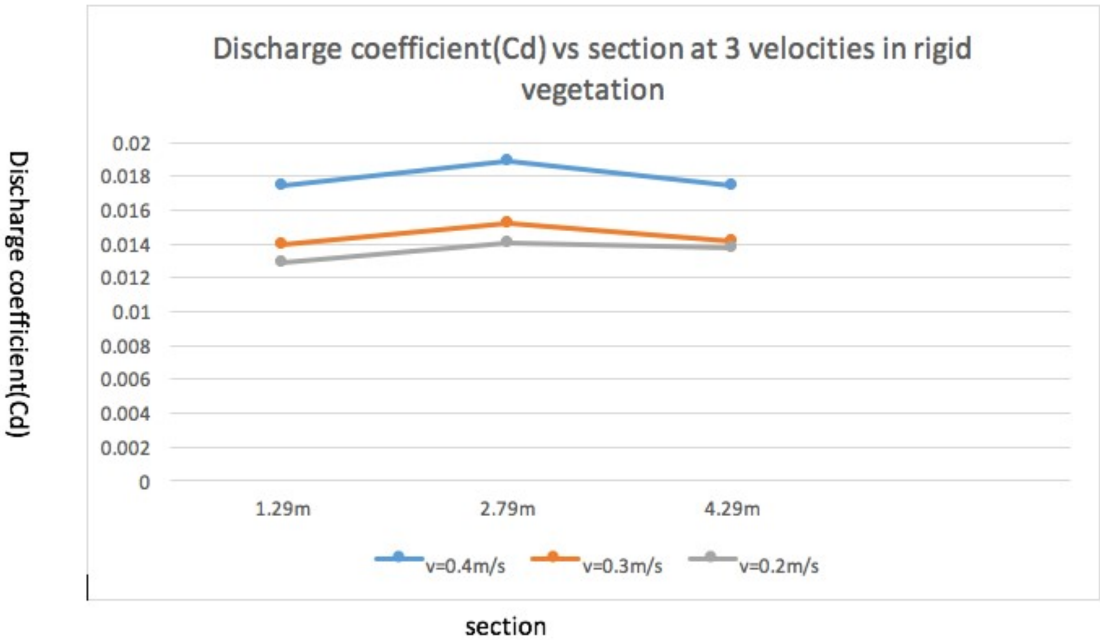

Fig. 36. Discharge Coefficient for Rigid Vegetation

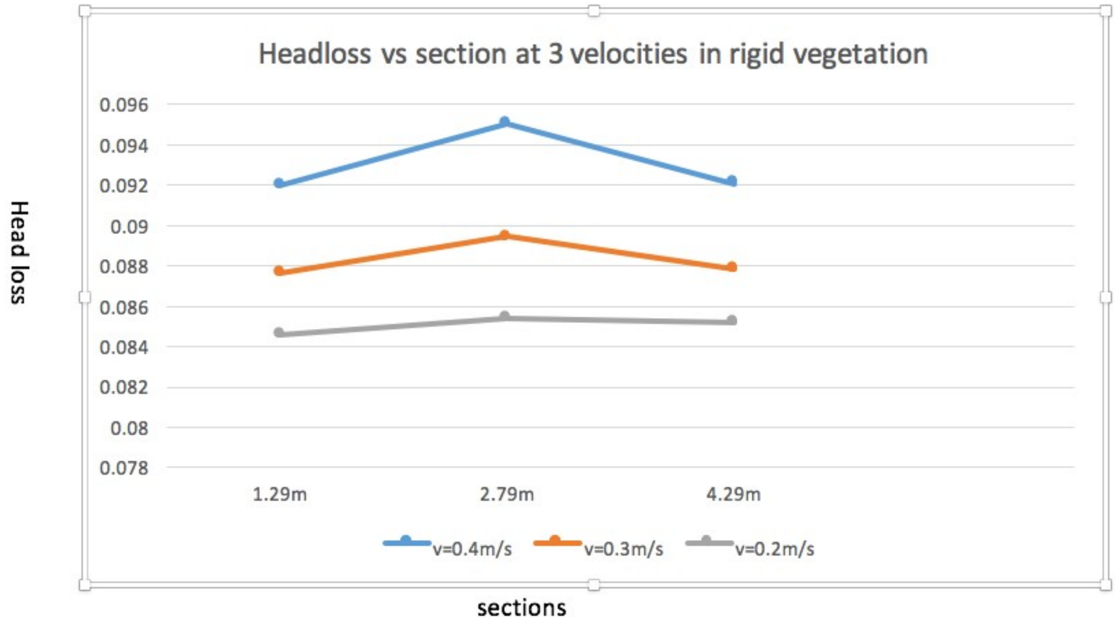

Fig. 37. Head Loss for Rigid Vegetation

Results obtained for Flexible Vegetation

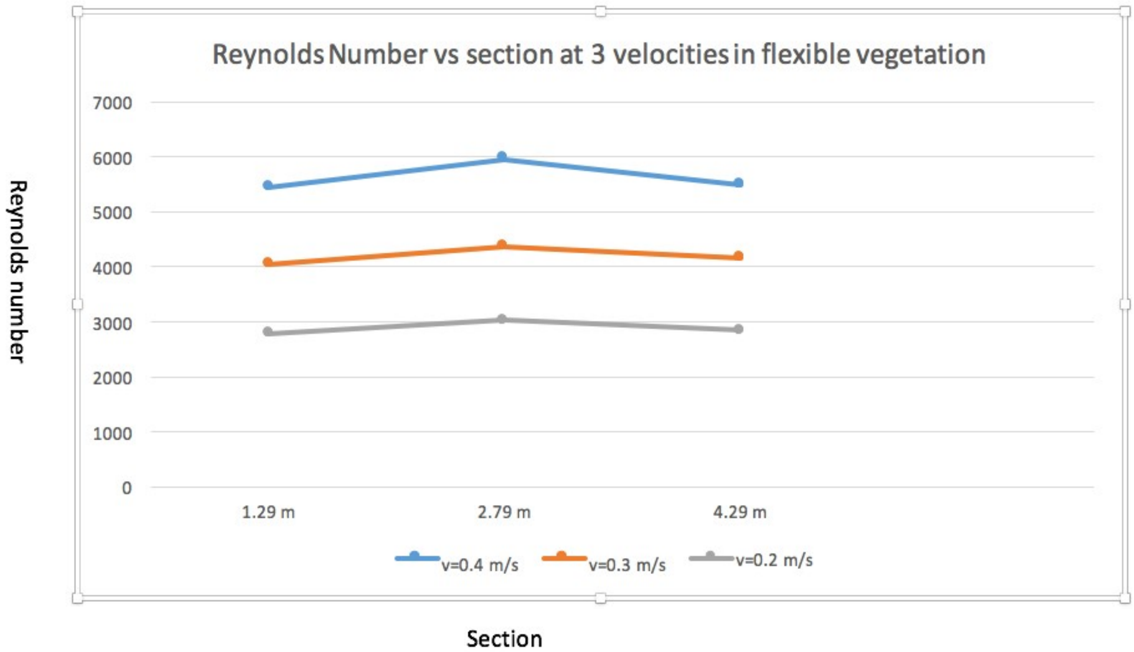

Fig. 38. Reynold's Number for Flexible Vegetation

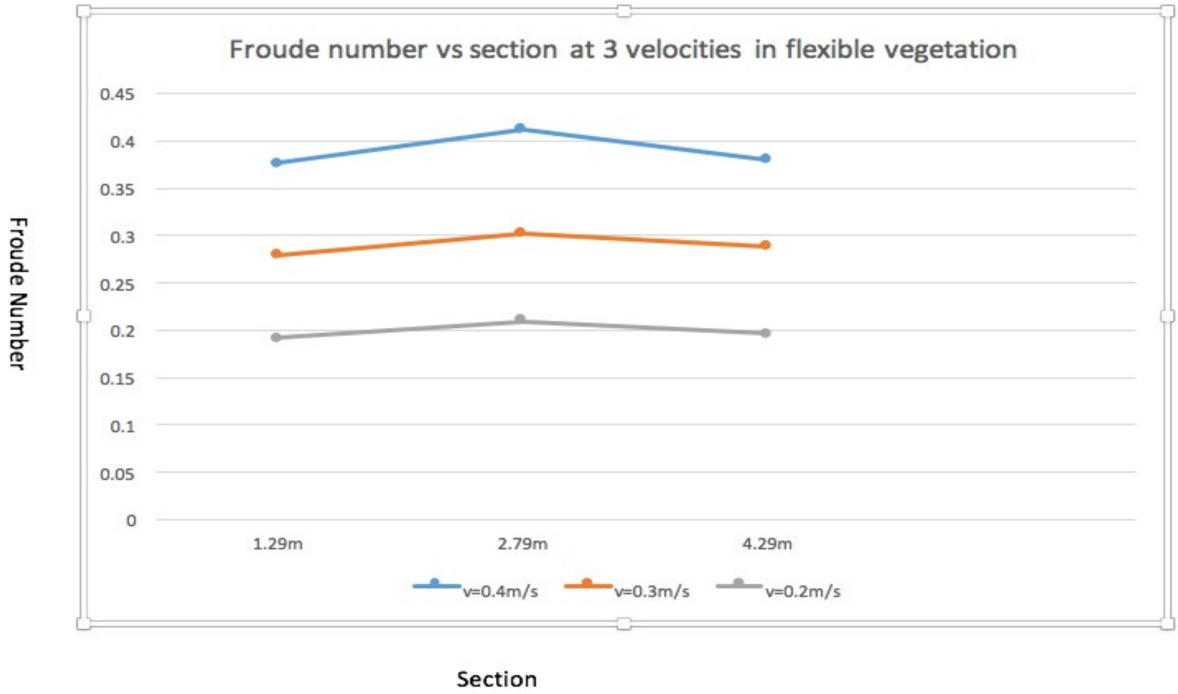

Fig. 39. Froude's Number for Flexible Vegetation

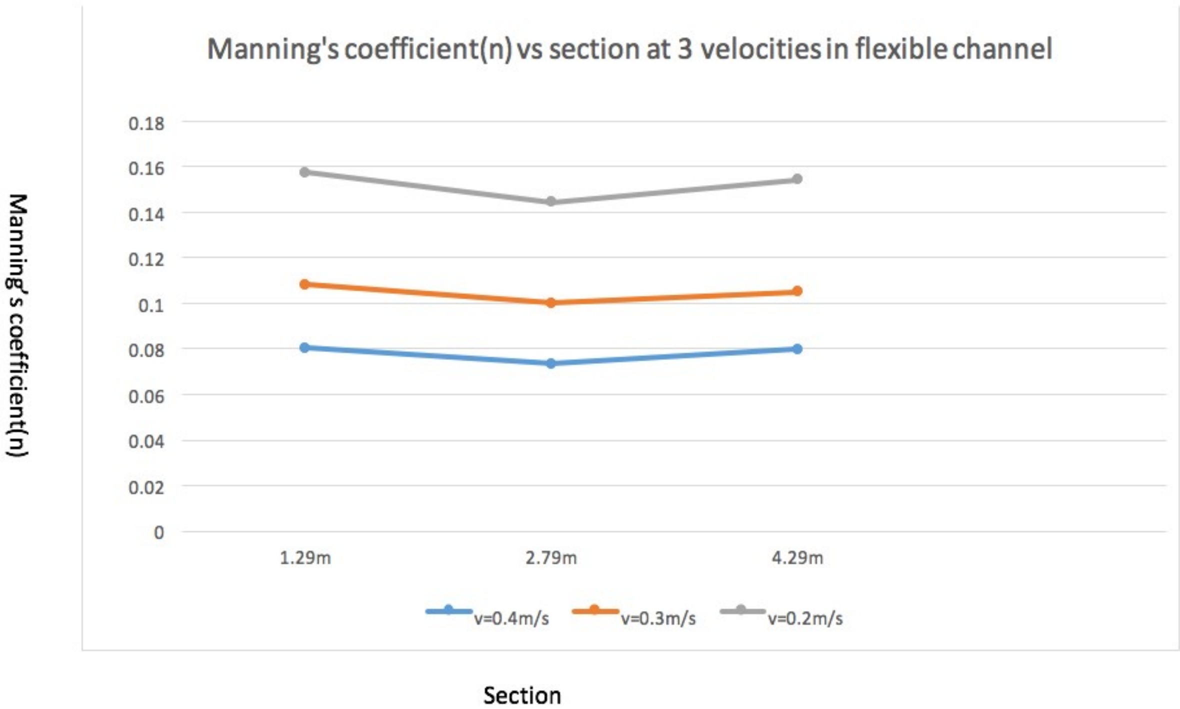

Fig. 40. Manings's Coefficient for Flexible Vegetation

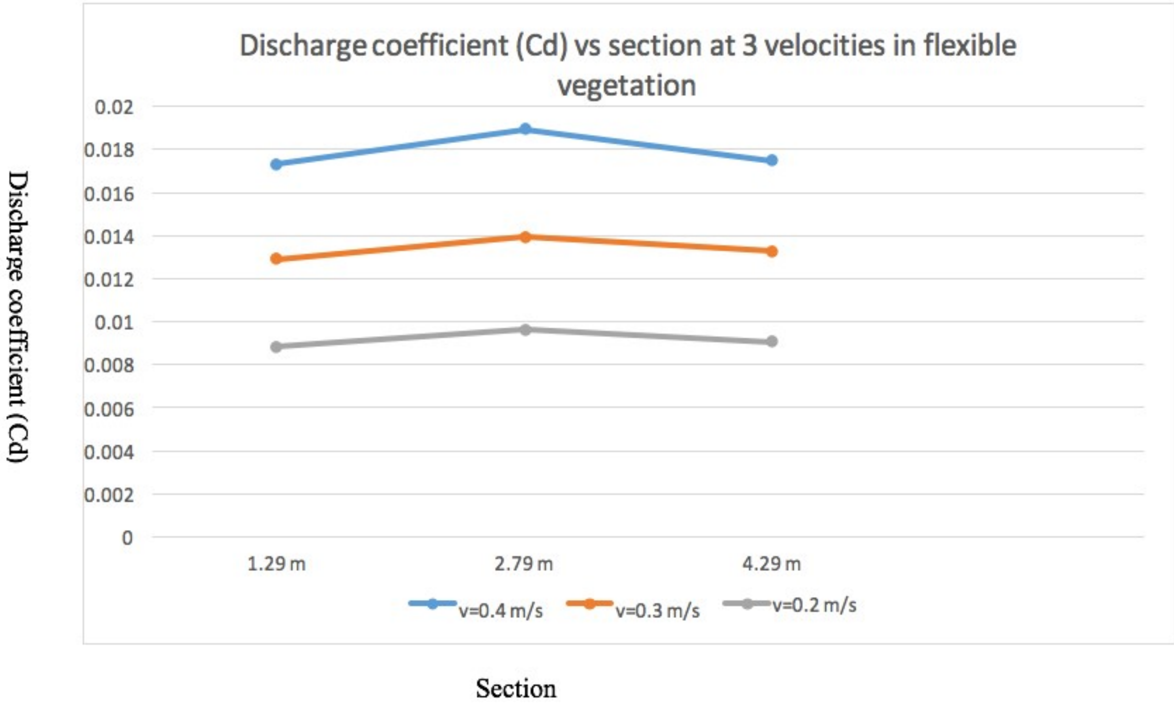

Fig. 41. Discharge Coefficient for Flexible Vegetation

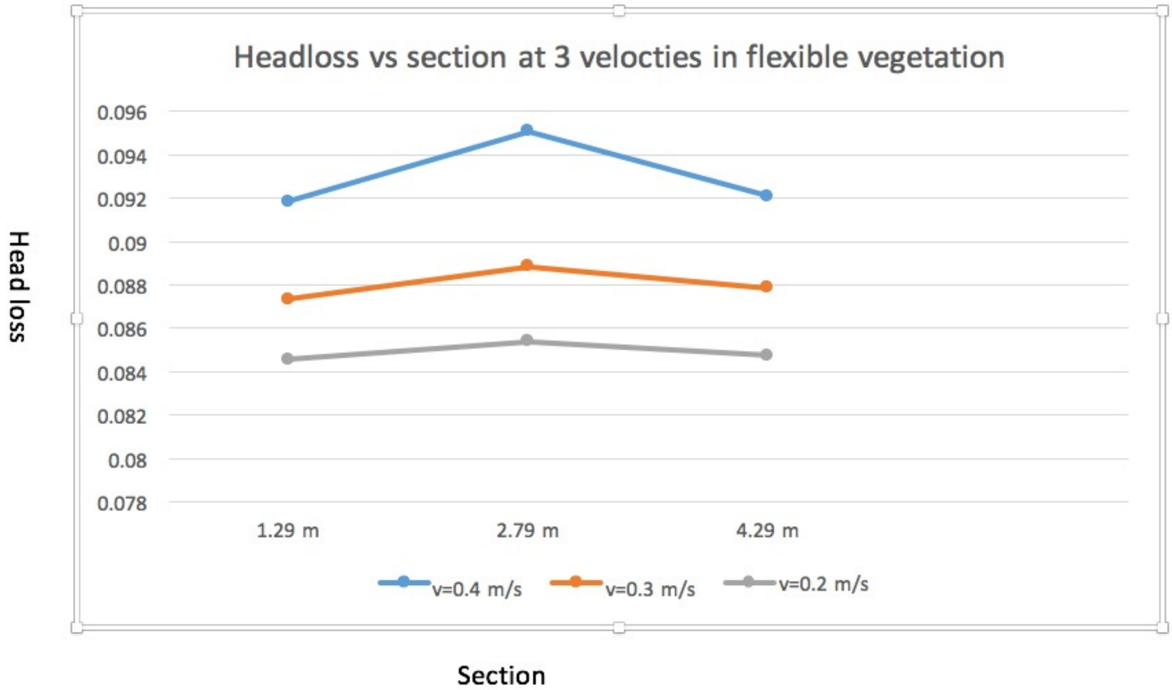

Fig. 42. Head Loss for Flexible Vegetation

CHAPTER – 5

CONCLUSION

Velocity and flow depth are calculated at three different sections on performing experiments and by using ANSYS Software. The results for both are found to be similar. This attempt was done by careful considerations of all the flow parameters while doing the experiment. The result concluded that resistance offered by rigid vegetation was more as compared to that in flexible vegetation. After this by making use of these flow depths and velocities five more parameters were computed to determine the characteristics of the flow. The objective was to draw comparison between rigid and flexible vegetation with the help of these parameters. The results showed that the Reynold's Number obtained was seen highest for 0.4 m/s velocity for flexible vegetation, as high as 5955.8 confirming turbulence at highest discharge unlike for rigid vegetation. Froude's Number was observed from 0 to 1 for both the cases. Also, low values for Coefficient of discharge and Manning's coefficient explained low resistance offered during the flow for flexible vegetation unlike in the case of rigid vegetation where, there was much resistance offered to the flow. Lastly, Head Loss at every section was observed quite low explaining that the water lost during the experiment at every section was less.

CHAPTER – 6

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