Investigating the Combined Effect of Tall and Short Vegetation Patches in Open Channel Flow

Saad Anwar[1]*, Naveed Anjum [1], Ahmad Ali [1], Saeed Shah [1], Imtiaz Ahmed [1], Zaheer Ahmad [1] and Junaid Ahmed Sidiqy [1]

[1] Khawaja Fareed University of Engineering & Information Technology (KFUEIT), Rahim Yar Khan, Pakistan; saadanwar450@gmail.com; naveed.anjum@kfueit.edu.pk; theahmadali268@gmail.com; saeedshah22215@gmail.com ; iimtiazahmed912@gmail.com; dr.zaheer@kfueit.edu.pk; junaid.ahmed@kfueit.edu.pk

* Correspondence: saadanwar450@gmail.com

Abstract

Double-layered vegetation patches in open channels have a significant effect on flow structures. While several investigations have been conducted on double-layered vegetation, none have specifically addressed the impact of submergence levels. This study employs a Reynolds stress turbulence model to examine rigid, discontinuous double-layered submerged vegetation patches. For simulations and post-processing, ANSYS (FLUENT) utilizing Computational Fluid Dynamics (CFD) techniques was used to analyze the differences in mean stream velocity within the model domain. Various distributions and profiles of mean stream and depth-averaged velocities are presented in this study. It was observed that the velocity decreases noticeably in the gap region, as the flow stabilizes there. Additionally, fluctuations in mean stream velocity were noted directly behind both the smaller and taller vegetation dowels. Notably, distinct velocity transition zones consistently detected at the tops of the vegetation dowels. Experimental vegetation patches should be installed along riverbanks, wetlands, or in storm water channels to monitor their effects on flow velocity.

Keywords: Double-layered, discontinuous Patches, ANSYS FLUENT, Simulations, Velocity distribution.

1. Introduction

Understanding flow evolution within vegetated channels is essential for hydraulic engineers. Vegetation plays an important role in shaping hydrodynamics of rivers, streams and man-made channels. Marine vegetation significantly mitigates mean stream velocity as compared to non-vegetated zone [1]. The presence of discontinuous layered vegetation in marine atmosphere remarkably alter the turbulent behavior of the flow in open channels. In natural streams, vegetation tends to occur in fragmented clusters that interact with flow in a highly non-linear manner [2]. In aquatic ecologies, vegetation patches contribute significantly to flow dynamics. They can mitigate wave energy and obstruct local fluctuation. Thus, vegetation patches act as a buffer to prevent erosion in swamp areas. Patchy vegetation provides a friendly environment and species jumble, and offer stable zones while minimizing bottom shear forces [3].

[Cotton] and [Naden] examine the effect of vegetation patches on velocity and turbulence characteristics in open channel. [Zhao] examine the influence of spatially fragmented submerged vegetation on turbulence within an open channel. [Huai] Suggested an analytical model for distribution pattern of longitudinal velocity in an open channel with double-layered vegetation. [Kim] offer a

 https://doi.org/10.64615/fjes.1.Special Issue.2025.48

numerical investigation of flow through rigid emergent vegetation by executing large eddy simulations. [Xia] and [Shih] experimentally examined the characteristics of flow in open channel with vegetation. They examined the hydrodynamic properties under open channel conditions with the help of various arrangement of vegetation. [Sukhodolov] and [Maltese] concentrated on the spatial patterns of turbulent structure that evolved on submerged vegetation patches.

[Liu] and [Shan] examined the streamwise velocity distribution along the channel length of inflexible, emergent, consecutive vegetation allocate in the middle of river through experiments. They suggested an analytical model for forecasting the longitudinal profile inside vegetation for inflexible, emergent and consecutive vegetation group. [Anjum] carried out numerical simulation of flow characteristics of finite double-layer inflexible vegetation group spread on the half width of open channel. Their study exposed that the flow characteristics of double-layer non-emergent vegetation group is more composite than the emergent vegetation group.

The effect of vegetation on flow structures have been investigated by a number of researchers by applying different type of numerical models. Non-submerge and submerge inflexible vegetation was analyzed for drag co-efficient [16]. Past researches mostly concentrated on continuous vegetation collection, even experimentally and numerically simulations of vegetation patch have concentrated on single vegetation patch [17], [18]. Large eddy simulation method was adopted to examine the stream vise velocity, turbulent kinetic energy and vortices profiles of single vegetation patch with different densities [19]. Past studies focused on sub-merged and emergent vegetation patches to determine the flow properties that are not enough. This study focused on four double layered submerged vegetation patches.

The purpose of this study is to create a model to investigate the influence of vegetation patches configurations on flow properties. The objective of this study is to clarify the velocity difference between vertically discontinuous double layer submerged vegetation patches. The research will focus on understanding the hydrodynamic interactions between vegetation patches and flow characteristics, with potential applications in river engineering.

2. Materials and Methods

2.1. Numerical Model

Reynolds Stress Turbulence Model is adopting in this study to simulate the model. The Reynolds Stress Model (RSM) is an advanced turbulence model used in Computational fluid dynamics (CFD) to predict turbulent flows. Unlike simpler model like K-Ɛ or k-ω, which assumes turbulence is isotropic, RSM directly solves for the Reynolds stress tensor, making it more accurate for complex, anisotropic turbulence. The Reynolds stress model offers superior accuracy in anisotropic and complex turbulent flows, but its computational cost and convergence issues make it challenging to use in many practical cases. For most industrial applications, hybrid models like k-ω SST or LES (Large Eddy Simulation) provide a better balance between accuracy and efficiency.

2.2. Conditions of Experiment

In this study, the flow condition for an open channel is assumed to be subcritical. The Froude number in open channel remained in the range of 0.2 to 0.4. To align these conditions, two various depths are taken. The flow velocity is calculated by $Fr= V/\sqrt{gz}$, where Fr is Froude number, V is velocity, g is acceleration due to gravity (m/s^2) and z is depth of flow. Discharge is determined by Q=A.V, A is the cross-sectional area (m^2) and V is velocity (m/s).

2.3. Setup of Numerical Model Domain

Model domain was meshed in ANSYS-FLUENT. The model was refined to 0.35 million nodes. A tri-pave unstructured mesh was used to display the geometry. After completing the process of modeling and meshing, Fluent was used for simulations of model domain. Periodic boundary condition was applied to the model. Boundary conditions include, top surface was designed to symmetry, the side walls and bed was designed to wall conditions, inlet and outlet was joined and designed to periodic conditions.

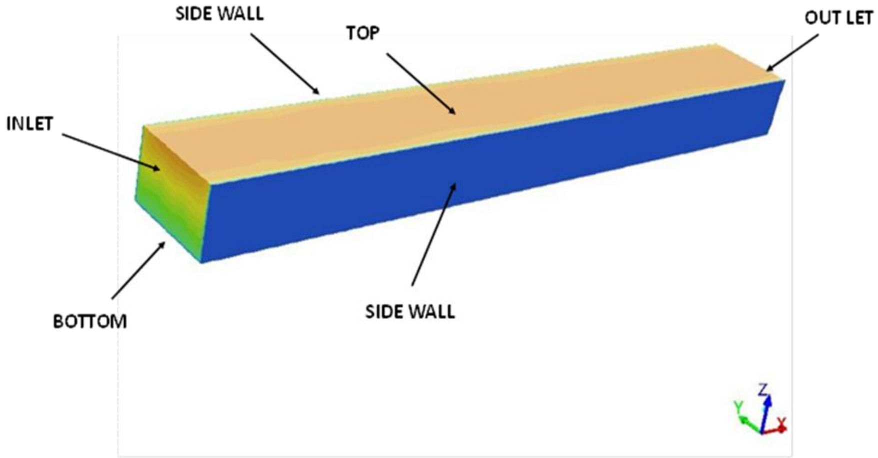


Figure 1. Boundary conditions of numerical model

2.4. Details of Model

The simulations of our study were conducted using ANSYS FLUENT, with a scale of 1:100 applied to the model. The study primarily focuses on analyzing the velocity parameters in the presence of vegetation. To represent the channel, a 3D model was created, measuring 2.28 meters in length and 0.3 meters in width. Within the model, four patches of vegetation were developed. Diameter of vegetation is 0.00635 m.

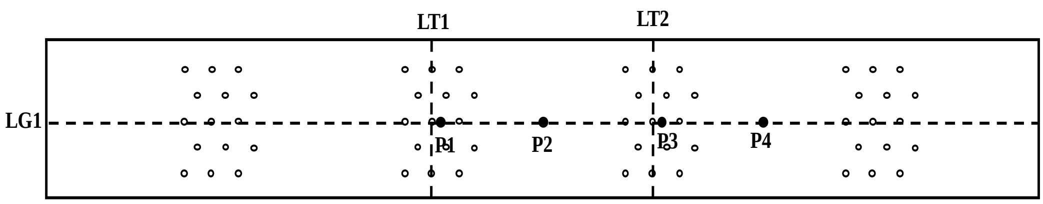


Figure 2. Top view of Model (Longitudinal Section LG1 at Y=15cm)

Table 1. ht and hs are the height of cylinders, St/d is the taller vegetation spacing and Ss/d is the smaller vegetation spacing, Q is the discharge, z is the depth of water, u is the velocity, Fr is the Froude number, Re is the cylinders Reynolds number and Re* is the flow Reynolds number.

Case	Vegetation	ht (cm)	hs (cm)	Q (L/s)	Z (cm)	u (m/s)	Fr	Re	Re*
1	Tall+Short	15.2	7.6	10.84	11.4	0.317	0.3	2003	35965

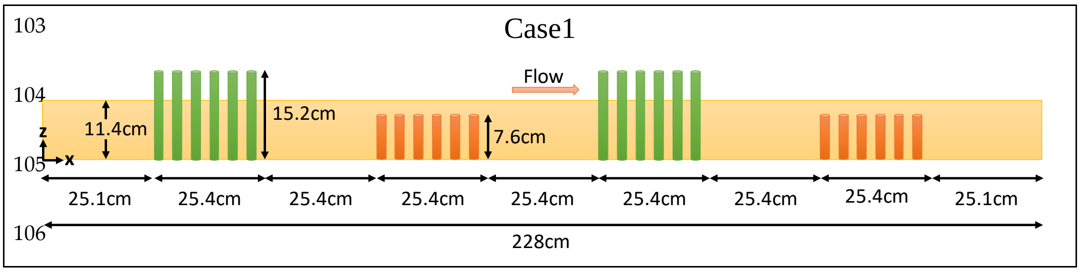


Figure 2. Side View of Model

3. Results and Discussion

3.1. Distribution of velocity contours

Velocity contours on XZ-plane as shown in figure, revealed the difference of velocities between vegetated and gap region. Maximum velocity was observed at the top of short vegetation. Maximum velocity was observed 0.38 to 0.44 m/s as shown in fig 3. Around the vegetation, velocity is observed zero. Velocity at near bed was 0.19 to 0.23 m/s, which reduced the scouring of bed.

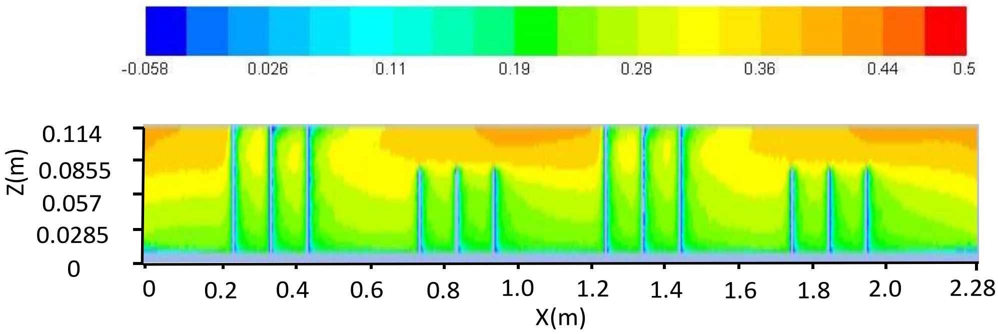
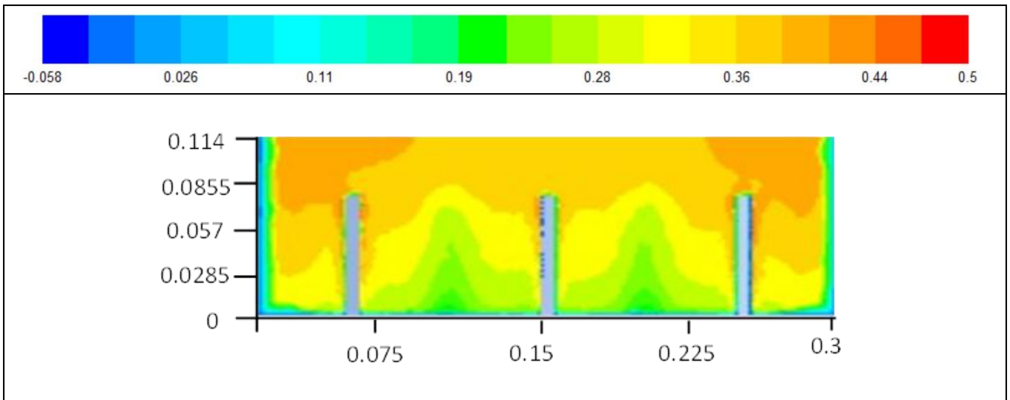
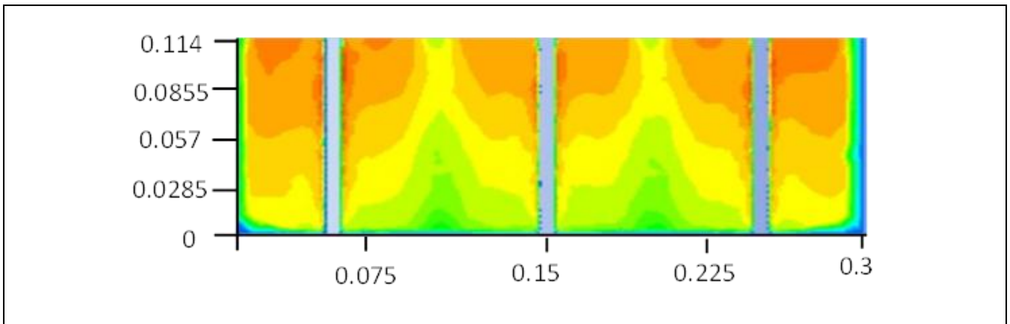


Figure 3. Velocity contours of Model Domain

Lateral sections taken at two zones (LT1 and LT2) shown in fig 2. The velocity contours on YZ-plane validate the results achieved from XZ-plane. The velocity was zero at vegetation in both sections as shown in fig 4(a) and (b). Maximum velocity was observed 0.39 to 0.45 m/s at the top of vegetated dowels.



(a)



(b)

Figure 4. Velocity contours of LT1 and LT2

3.2. Mean-stream Velocity

In open channel, four points were selected to examine the difference of velocity as shown in fig 2. The velocity profiles of these points were shown in Fig 5. At point P1, velocity increase at the top of vegetation due to smaller vegetation. At point P2, velocity increase due to gap region. Velocity was minimum at point P3 due to taller vegetation. At point P4, velocity was constant because flow was developed. Velocity was minimum near the outlet because the flow becomes stable.

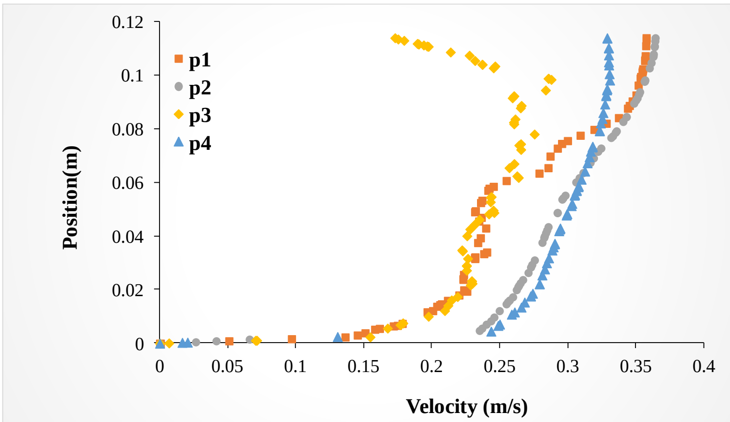


Figure 5. Profile of Mean-stream Velocity at P1, P2, P3 and P4

5. Conclusions

The response of the flow interacting with double-layered and spatially fragmented vegetation within a rectangular open channel was examined through computational modeling. To replicate flow dynamics in this study, a Reynolds stress model was utilized. The analysis focused on how varying vegetation structures, double-layered and discontinuous patches impact the average longitudinal velocity, as interpreted through contour plots.

The averaged stream wise velocity exhibited a significant rise near the top of vegetation and remained relatively stable throughout both the taller and shorter vegetation. An increase in velocity was observed close to the channel bed, while a notable velocity shift occurred just above the smaller submerged vegetation structures.

Higher velocities were detected within the vegetation zones compared to the gap regions. These findings suggest that the gap regions serve as favorable sites for sediment deposition and also support aquatic ecosystems due to suitable physical conditions.

Overall, the results confirm that flow behavior through fragmented and double-layered vegetation is inherently variable. This investigation provides valuable insights that can support better interpretation of flow characteristics in natural or artificial channels containing patch-type and layered vegetation.

Funding: This research received no external funding.

Conflicts of Interest: The authors confirm that there are no known conflicts of interest associated with this publications.

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