EXPERIMENTAL STUDY OF OPEN CHANNEL FLOWS WITH TWO LAYERS VEGETATION

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ABSTRACT

Vegetation in river bed has a great impact on flow characteristics in rivers, especially during floods. Understanding the structure of flow in vegetated open channels, in both submerged and emergent conditions, would provide valuable scientific basis for evaluating the effect of vegetation on river flows. This paper studies the structure of the open channel flows with two layers vegetation through experiments. The experiments were conducted at Nanjing Hydraulic Research Institute (NHRI), in a 12 m long by 0.4 m wide straight flume with a rectangular cross-section at a constant slope of 0.004. The vegetation was modeled by dowels with 6.35 mm diameter at two different heights of 100 mm and 200 mm, which was configured with different patterns and placed over a 10 mm thick plate on the bed of the flume. The artificial vegetation covered a 7 m long portion of the flume. In our study, various flow depths were taken to cover both emergent and submerged flow conditions. The measurement locations have been chosen in certain key sections of the vegetation region such as free flow region, behind short and tall dowels.

The experimental data showed that the velocity profile is mostly uniform over the depth in the both emergent and submerged cases, except location 1 (directly behind tall dowel) in a submerged condition. The flow velocity in the vegetation layer is significantly smaller than that in the surface layer (i.e. non-vegetation flow layer). A near-constant velocity dominates in the vegetation layer and increases close to the interface at the top of short vegetation. There is a sudden change in the shape of the velocity profile near the top edge of vegetation. The results also showed that the flow velocity is strongly dependent on measurement locations.

Keywords: Vegetation, Submerged Vegetation, Emergent Vegetation, Two Layers Vegetation, Velocity Profile.

1 INTRODUCTION:

The flow resistance due to vegetation reduces the flow velocity, which leads to remarkable changes in physical and biological processes in aquatic environments. The influence of riparian vegetation on ecological and flow process in rivers has become an increasingly important aspect of river flood risk and environmental management. There are many studies on the characteristics of the flow that passes through the vegetation, and these studies mainly focused on vegetation with the same height, which is not as real as that in natural rivers and channels. There are only a few studies on flows with a double array of short and tall vegetation. Furthermore, most of the previous studies just are either in submerged or emergent flow conditions, but in rivers and natural channels vegetation has different heights and experiences both emergent and submerged conditions together.

Although the flow velocity profile in vegetated open-channels has been studied experimentally and analytically in the literature, it cannot merely correlate with a large variety of flows and vegetation configurations. In previous studies, logarithmic law or power-law distribution is used to describe the velocity profile in the zone above the vegetation. However, in shallow flow conditions, a large portion of the flow above vegetation may be characterised more appropriately as a roughness sublayer rather than an inertial sublayer where logarithmic law 3 applies. Within a roughness layer, the local imbalance between the production and dissipation of turbulence transport invalidates the logarithmic profiles (Nepf et al. 2007).

Vegetation would change the velocity profile and some other characteristics of the flow. Previous experimental studies can be categorised into two different groups. One group of researchers conducted real and natural vegetation as experimental material and the other used rigid cylinders to simulate vegetation (Tsujimoto and Kitamura 1990; Nepf 1999; Carollo et al. 2002; Nezu and Sanjou 2008).

Based on Nezu and Nakagawa's studies, in normal open channel flows without any vegetation, vertical velocity distribution is logarithmic (Te Chow 1959; Nezu and Nakagawa 1993), as skeched in Figure 1.

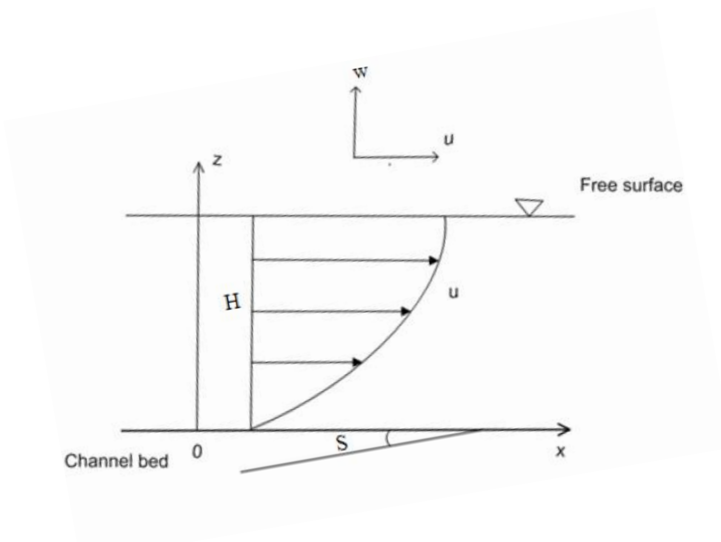


Figure 1. Velocity profile in open channel flow without vegetation.

Nevertheless, the vegetation adds resistance, induces drag forces and can cause significant changes in velocity profile.Vegetation inside a channel can be either emergent or submerged. As it can be seen in Figure 2, in emergent condition the velocity profile can be uniform according to the depth (Tsujimoto and Kitamura 1990; Stone and Shen 2002). In submerged condition, the velocity profile followed an S-shaped pattern (Kouwen et al. 1969; Temple 1986; Ikeda and Kanazawa 1996; Carollo et al. 2002).

Stone and Shen (2002) pointed out that the submerged condition is always more complicated than the emergent condition. It should also be mentioned that the velocity in the surface layer is substantially larger than that in the vegetation layer (Stone and Shen 2002).

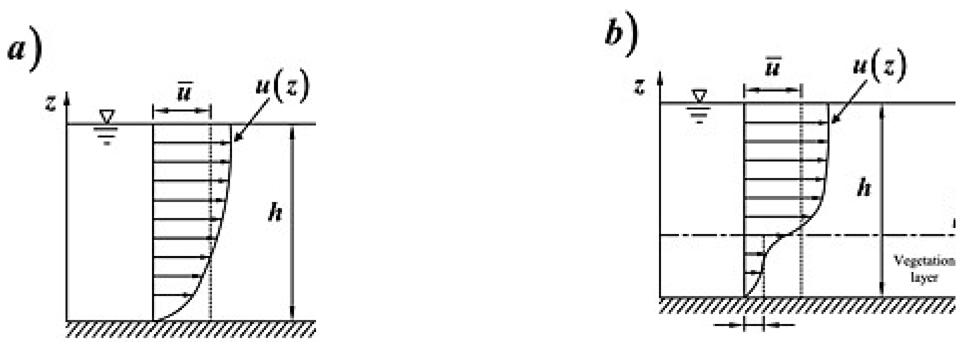


Figure 2. Velocity profile in a) Emrgent and b) Submerged condition.

Liu et al. (2008) did some experiments with rigid cylinders in Virginia Polytechnic Institute, where they used LDV(Laser Doppler Velocimeter) to measure the velocity in different locations within the vegetation area . They noticed that in both submerged and emergent conditions, the velocity through vegetation is dependent on vegetation spaces and density. In denser areas, the velocity is different in different locations and depth, but in the case of low-density vegetation, with less number of vegetation, the velocity varies remarkably. Based on their experiments, the velocity inside the vegetation layer changes slightly followed by a rapid increase near the interface (Figure.3).

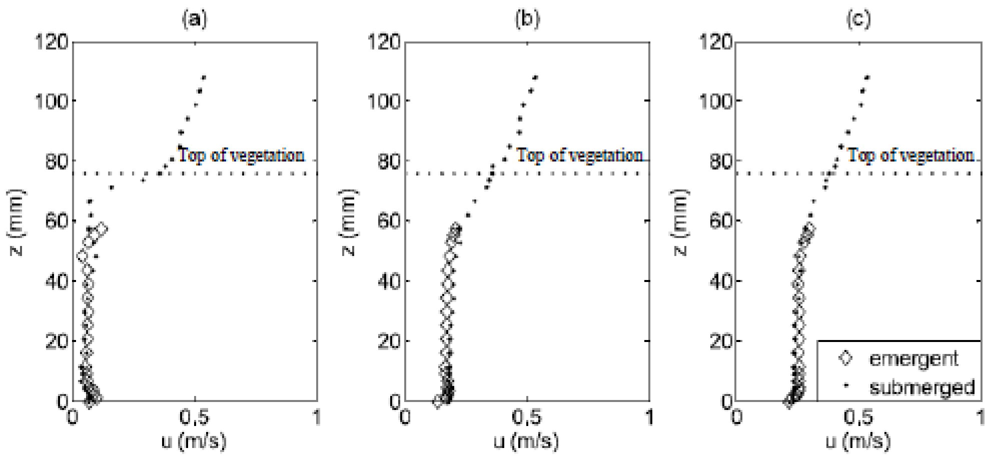


Figure 3. Comparison between submerged and emergent condition based on Liu et al. (2008) experiments.

Based on our review, although many studies have been done on the flow characteristic through the vegetation simulated by circular dowels, the studies in high Reynolds numbers are very limited. It would be hard to achieve the uniform flow within the vegetation in the supercritical flow with the high Reynolds number, but during our experiments some cases have been obtained in the supercritical conditions and data could be useful for further studies. Equation [1] and [2] represent the Froude and Reynolds number respectively.

$$Fr = \frac{v}{\sqrt{gy}} \qquad [1]$$

where v = velocity of the flow, y = depth of flow above the channel bottom, and g = gravity.

$$Re = \frac{vd}{\nu} \qquad [2]$$

where v = velocity of the flow, d = flow depth, and ν = kinematic viscosity of the fluid.

2 METHODOLOGY:

All the tests have been performed at NHRI, in a 12 m long by 0.4 m wide straight rectangular flume at a constant slope of 0.004 (Figure 4). The vegetation has been assumed by cylindrical morphology, and so can be modelled by circular dowel cylinders (Figure 5). The rigid cylinder array is ideal for modelling the flow-vegetation interaction, as it has a reasonable morphological approximation of the stem region. A 10 mm thick plate with holes will be placed at the flume bottom to hold the dowels (vegetation) (Figure 6). A flow straightener device in the entrance section of the flume is used to minimise entrance effects on flows at the section tested. At the end of the flume, a tailgate of stop logs is used to adjust the flow depth and to ensure a uniform flow in the channel (Figure 7).

Figure 4. Flume

Figure 5. Circular dowels

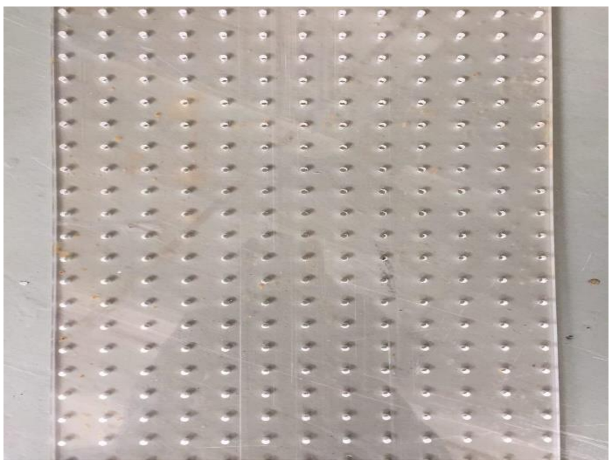


Figure 6. Plate

Figure 7. Tailgate

The artificial vegetation covered a 7 m long portion of the flume (Figure 8). The vegetation was simulated by 6.35 mm diameter cylindrical dowels (PVC rods) at two various heights of 100 mm and 200 mm (Figure 9).

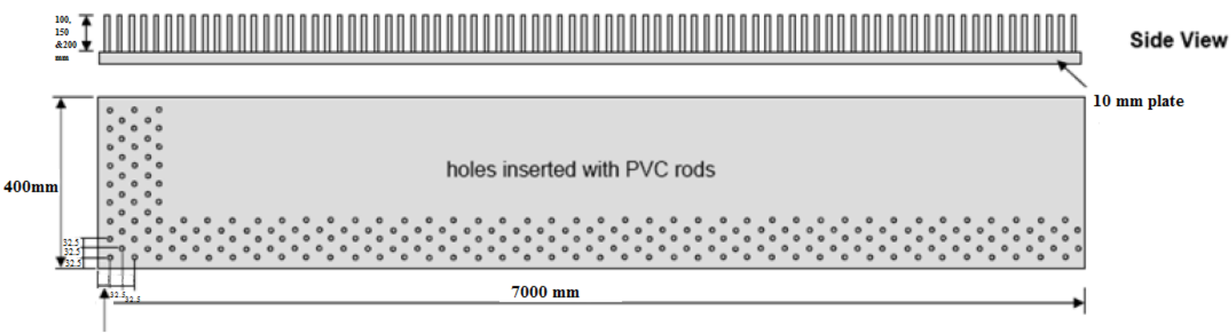
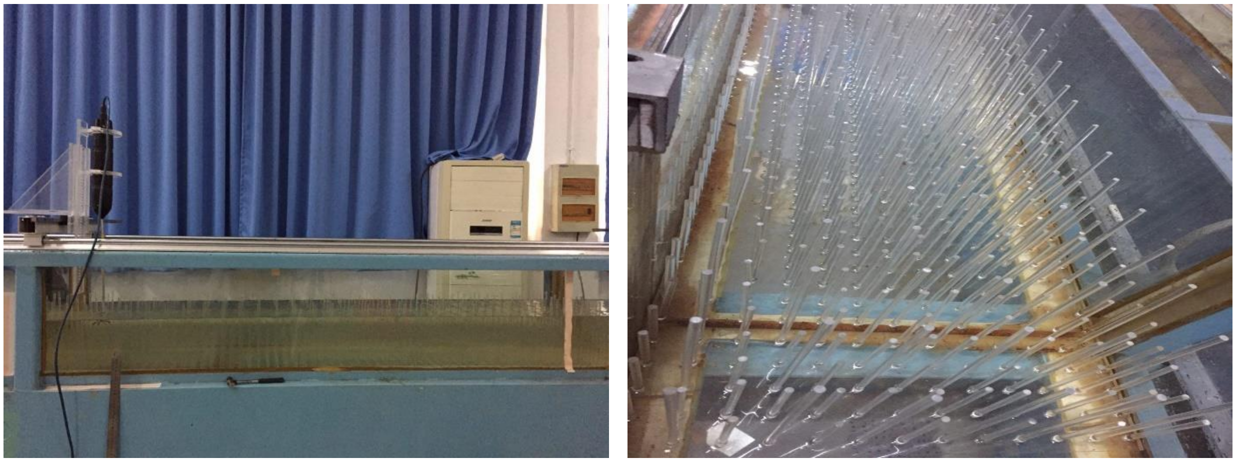


Figure 8. Sketch of vegetation portion

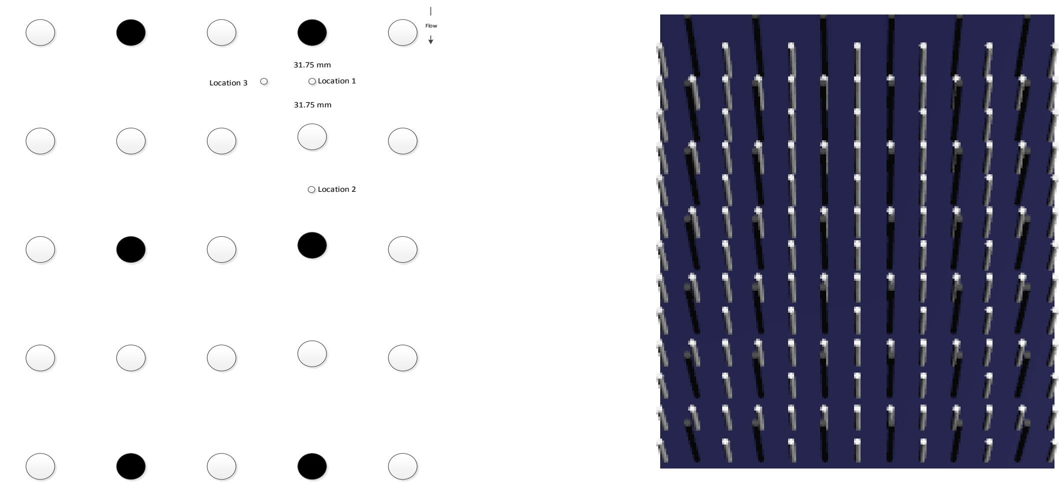


a b

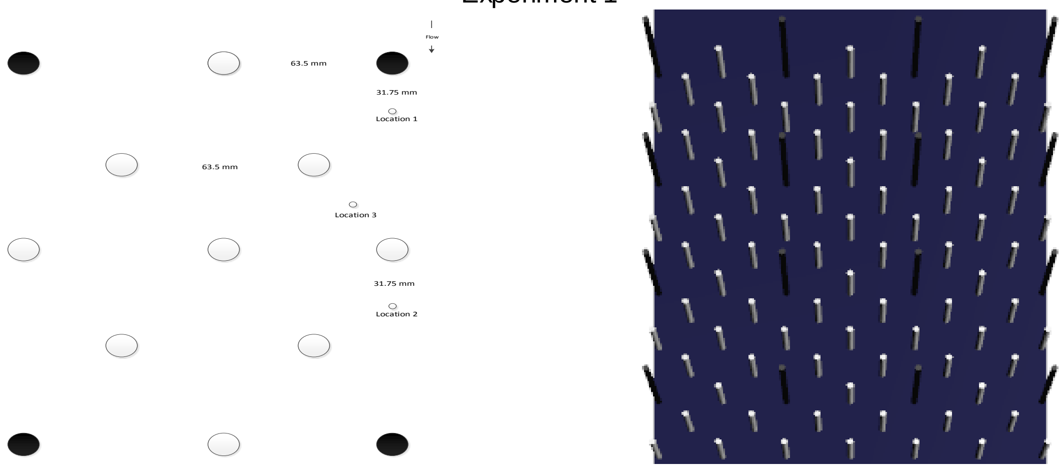
Figure 9. The dowel formation in the flume.

Four experiments were done under different types of formations and spacing. The flow depth is based on a simple rule, which makes the shorter vegetation entirely submerged and the tall ones remain emergent. The spacing is a major factor for dowel configuration. Three different spacing of 31.75, 63.5 and 127 mm was used in the experiments. Vegetation in natural channels is usually denser in the lower layer but sparser in the upper layer; the taller vegetation often grows near the wall of the channels, and the shorter one is observed more in the inner sides of the channels (Nepf, 2007).

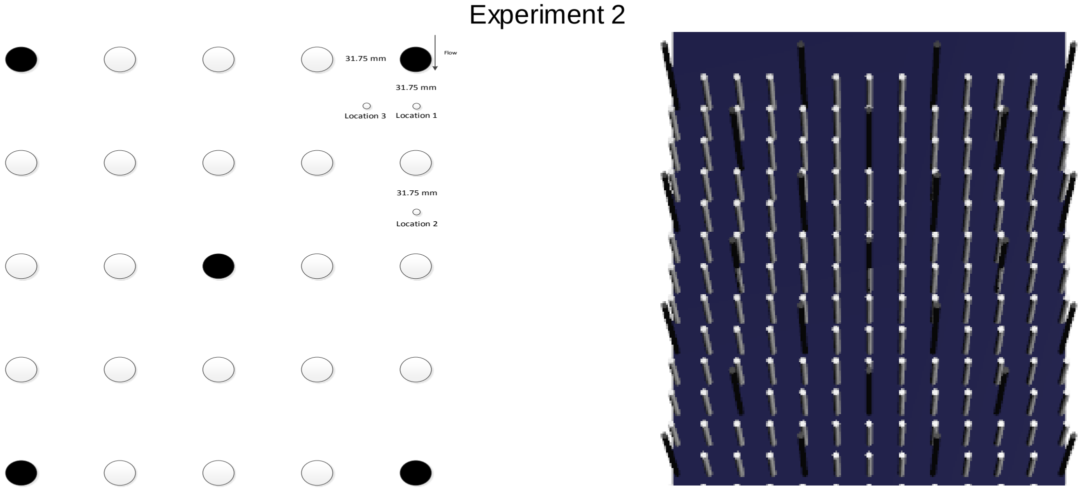
This study will focus on the effect of vegetation density and array on flow velocity, so various types of formation and experiments have been designed. The dowels can be placed in both linear and staggered formation and also in a way that has not ever been studied before. Our experiments were arranged into four different types based on height, arrangement and number of dowels. We did measurements at multiple locations within the vegetation to observe the velocity changes as water passes through a vegetation array simulated by rigid dowels. The measurement was done along verticals at certain locations selected to serve as a template to provide an adequate representation of the flow conditions and their variability anywhere within the vegetation array. The main aim of this paper is to examine how the velocity is affected by simulated vegetation arranged in mixed layer formation. Figure 10 shows the schematic arrangement of vegetation in experiment type 1 to 4, in which black and white circles represent tall and short dowels respectively, while small circles indicate the location points of measurement. In all four experiments location 1, 2 and 3 represents the point behind the tall dowel, behind the short dowel and in open region area, respectively. The details of each experiment is given in Table 1, which shows that all four experiments are in supercritical and fully turbulent flow conditions, as Froude number is more than 1 and Reynolds number is more then 10000 (Sinnott, 2009).



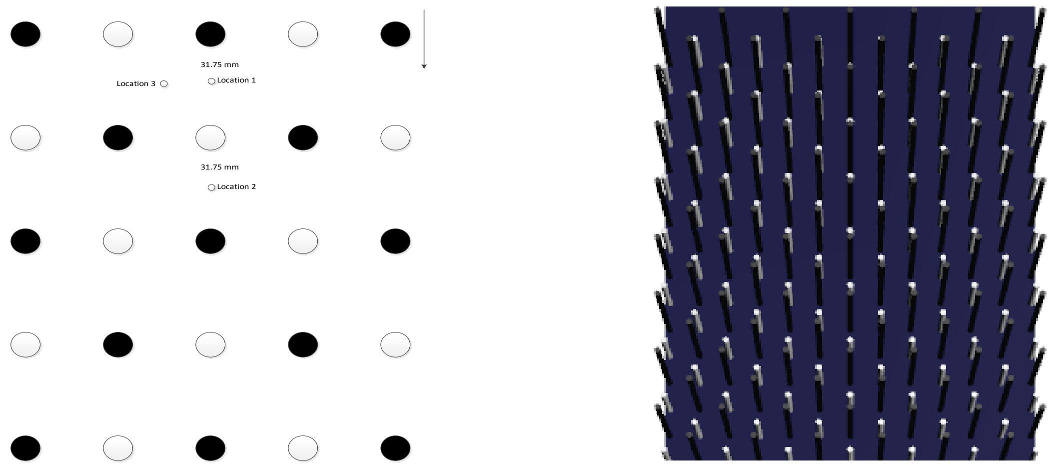
Experiment 1



Experiment 2



Experiment 3



Experiment 4

Figure 10. Dowel arrangement for experiments 1-4. The black and white circles represent tall and short dowels respectively. The arrow shows the flow direction, and o represents the measurement points by ADV.

Table 1. Summary of experiments.

Experiment	Dowel Height (mm)		Dowel Spacing (mm)		Dowel Arrangement		Depth of flow (mm)	Average Velocity (m/s)	Reynolds Number	Froude Number
	Short	Tall	Short	Tall	Short	Tall				
1	10	20	31.75	63.5	Linear	Staggered	17.6	0.8806	15499	2.11
2	10	20	63.5	127	Linear	Linear	16.8	0.9226	15500	2.27
3	10	20	31.75	127	Staggered	Linear	18.3	0.8469	15498	1.99
4	10	20	63.5	63.5	Staggered	Staggered	18.7	0.8288	15498	1.93

3 RESULTS AND DISCUSSION:

The measured data can provide us with a comprehensive view of velocity throughout the flow depth, for which the short dowels are completely submerged and the tall ones are emergent, and the measurement points are carefully selected in order to show velocity profile changes as water passes through the vegetation, see Figure 10. As shown in Table 1, the four experiments are in fully turbulent and supercritical conditions because $Re > 10000$ and $Fr > 1$.

Figures 11-14 show the velocity profiles of four experiments. The velocities at the locations immediately downstream of a dowel (Location 1 and 2) experienced a spike near the bed of channel and stayed constant over a certain depth of flow, which then followed by a rapid increase in velocity at the top of the short cylinder. Figure 11 to 14 also illustrate that location 3, which is located in the open region, had the highest velocity compared with other measurement locations. This indicates that the presence of vegetation has a remarkable effect on velocity.

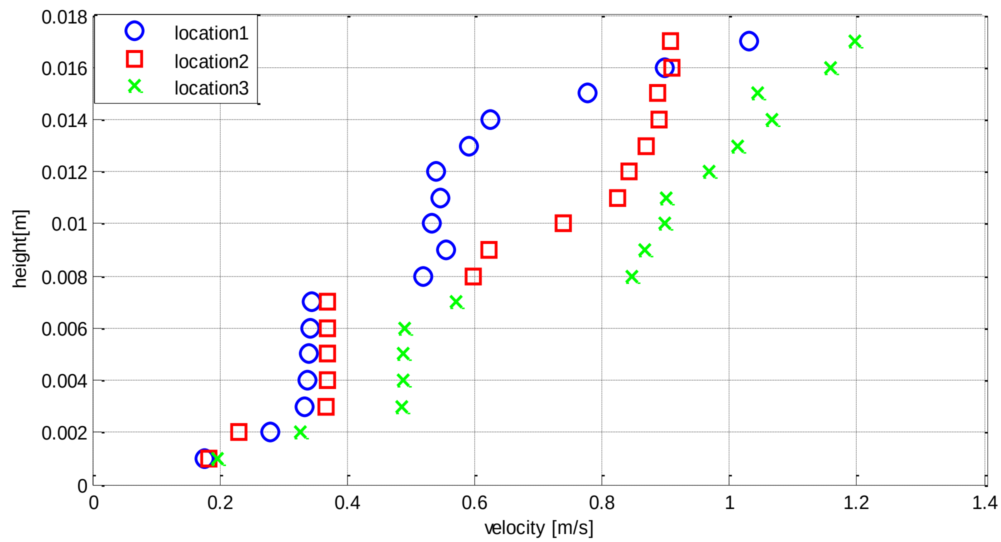


Figure 11. Velocity profile of Experiment 1.

Figure 11 shows the velocity profile of Experiment 1, where both the low and tall dowels are sumberged. As it can be seen the velocity profiles for all three locations remain almost constant after a rapid increase near the bed, and then followed by a substantial increase at the depth of 9.5 mm, which is close to the top of the short dowel. More specifically, the velocity in the open region increases almost linearly above the short dowel height while the velocity at lacation 2 (behind the short dowel) experienced a moderate increase. It can be seen that the presence of vegetation regardless to their height have some effects on the velocity profile. Location 1 (located behind the tall dowel) has the lowest velocity compared with the other locations in this experiment case.

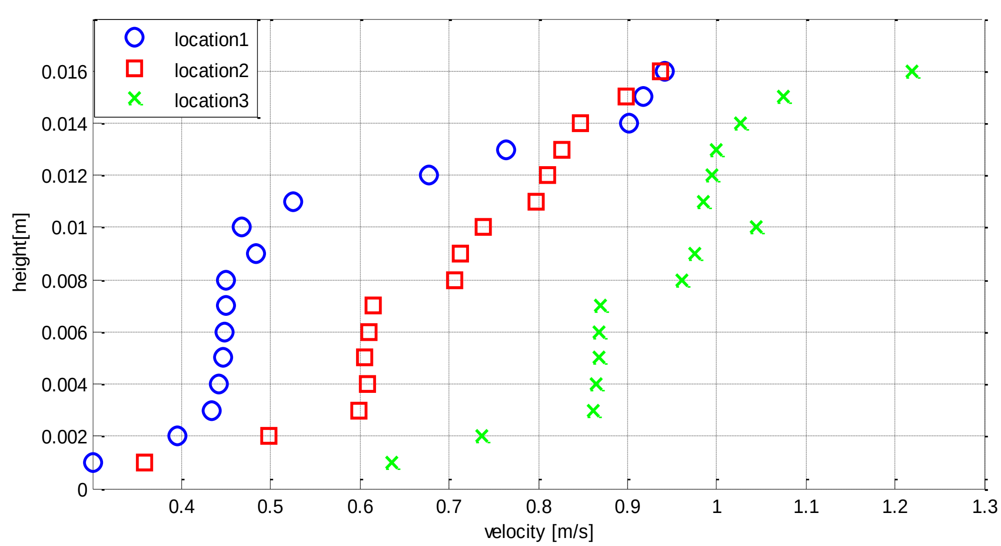


Figure 12. Velocity profile of Experiment 2.

Figure 12 presents the velocity profile of Experiment 2, in which the short dowel is submerged but the tall dowel is emergent. In this experiment, the space between dowels is sparser compared with other three experiments. Data can be compared to Experiment 1 to help understanding of the effect of vegetation spacing and density on the velocity profile of flow through vegetation. As it can be seen from Figure 12, the experimental data show considerably different velocity profiles from those in Experiment 1. At location 1 of Experiment 1, the velocity profile is almost constant over the short dowel height, while in Experiment 2, the velocity at location 1 appears a gradual increase throughout the short dowel height before a rapid increase near the top of the short dowel. The velocity in Experiment 2 is much faster than that in Experiment 1, which seems due to the difference of vegetation density. Furthermore, in sparser condition there exits much larger difference between the velocities of locations.

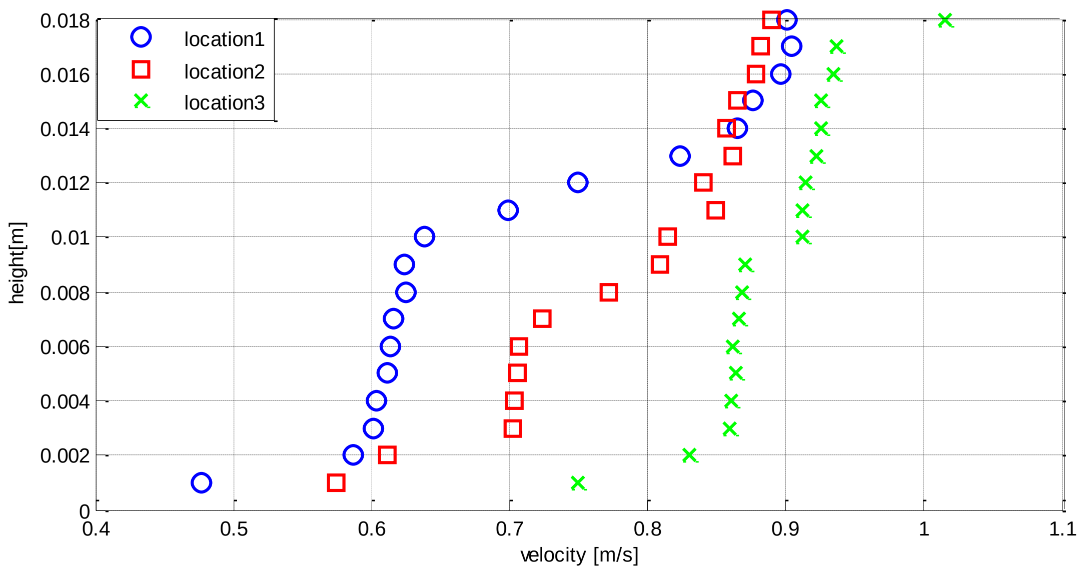


Figure 13. Velocity profile of Experiment 3.

The velocity profiles of Experiment 3 is shown in Figure 13, which shows the velocites of different locations at a different depth. Overall, although location 1 had the lowest velocity at a depth of 1 millimetres, but the trends have been changed during the experiment and at the highest measurement height, location 2 has the lowest velocity. On the other hand, location 3 had the highest velocity throughout the measurements in both emegent and submerged condition. Like Experiments 1 & 2, there is a significant rise in velocity at the edge of the short dowel. At the lowest measurement point, location 3 (located in the open region) has the velocity of about 0.74 m/s; then, the velocity increases rapidly to reach 0.86m/s and remain until the height of short dowel; afterwards, there has been a sharp rise to 0.92 m/s and then gradually increase until the depth of 18 mm where the velociy reaches about 1.02 m/s. The velocity profile for location 2 (behind the short dowel) starts almost 0.58 m/s, and then it is followed by considerable growth and at peak in almost 0.9 m/s. Overall, it should be memtiuoned that the trends of all three locations could be considered same with different velocities.

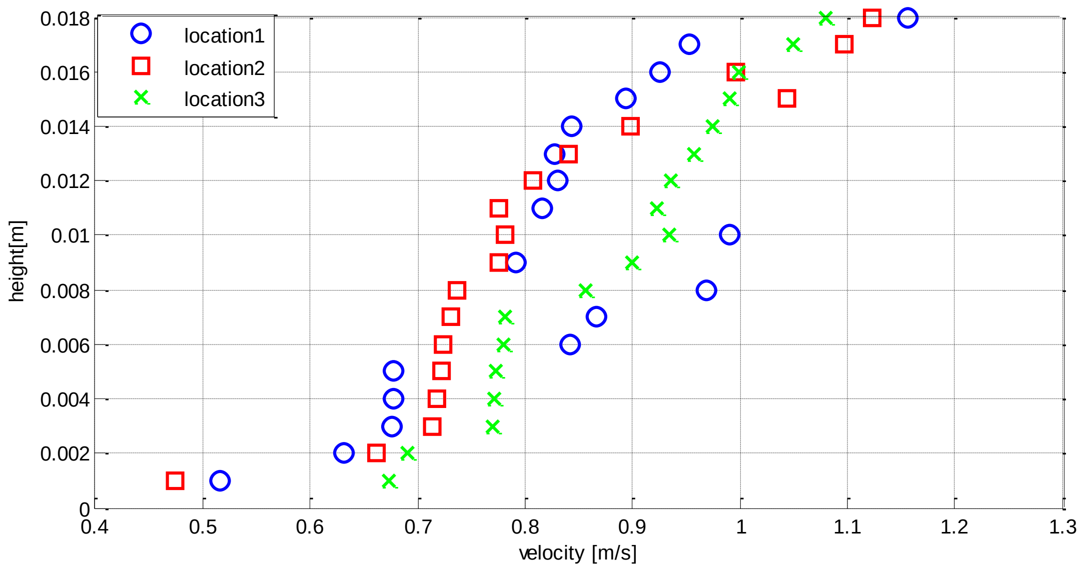


Figure 14. Velocity profile of experiment 4.

Figure 14 compares how velocity profiles of different locations change in Experiment 4, in which both dowels are submerged. Overall, although location 3 in the open region has the highest velocity through the short dowel height, but its velocity is lower than that at location 1 in the non-vegetation layer near the water surface. In Experiment 4, both short and tall dowels were arranged in staggered formation (Figure 10), the velocity profiles of all three locations have more fluctuations in comparison to other experiments. It is noted that location 1 has surged near the edge of short dowel, which may be due to strong vortex effect in the cylinders wake.

4 CONCLUSIONS

In this paper, the vegetation was modelled under two different heights, which are arranged in linear or staggered pattern, and various flow depths were used to cover both emergent and submerged flow conditions. The measurement locations were chosen in all important sections of the vegetation area, such as the open stream region, behind the short and tall dowels. The experimental results show the significant difference of velocity profiles at three selected locations for depth-limited open channel flow with mixing layer vegetation. Generally, the flow velocity inside the vegetation layer is much smaller than that in the surface layer (i.e. non-vegetation region). Almost in all four cases, a near-constant velocity dominates inside the vegetation layer and increases rapidly near the top of short vegetation, and then increase gradually to the water surface. There is a sudden change in the shape of the velocity profile near the top edge of vegetation. The results also showed that for all four experiments, the flow velocity is strongly dependent on measurement locations, and that vegetation spacing and density also play an important role in the velocity profile of vegetated channels.

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