Effect of Vegetation on the Flow of a Partially-Vegetated Channel

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Abstract. A vegetated channel commonly exists in the natural environment. Over recent decades, many researchers have taken an interest in this field. The hydraulic characteristics of flow over vegetated channels are complex. Vegetation significantly affects the flow resistance and turbulence, resulting in sediments, nutrients, and contaminants transportation. Thus, understanding the impact of vegetation on flow structures is important for river and environment management. However, most attention on vegetated channel flow focuses on single-layered vegetated channels. There are few studies on the impact of double-layered, partially placed vegetation on open channel flow. To fill this research gap, this paper aims to investigate the impact of vegetation on the flow velocity of a double-layered, partially placed vegetated channel.
Keywords: vegetated flow, double-layered vegetation, velocity profiles, open-channel flow, riparian environment.

1. Introduction

Vegetation commonly existed on river channels and affects bank stability, containments spreading, and sediment transport [1]. The existence of vegetation influences the flow structure on resistance and discharge, which leads to impacts on the environment and ecology. In recent years, there has been an increasing interest in related research [2-6], for example, the prediction of velocity profiles [7-9], the modeling of the lateral variation of velocity [10-12] in single-layered vegetation, and the experimental study of double-layered vegetation [12-15]. Vegetation affects flow structure, such as flow resistance, velocity profiles, and turbulence intensity.

White and Nepf [4] presented a model to predict velocity profiles, shear stress, and boundary layer width in a partially vegetated shallow channel, where the vegetation was modelled by wooden cylinders. They stated that the flow is dominated by a two-layer flow structure, with high shear stress across the vegetation interface and a more gradual boundary layer outside the vegetation. Chen et al. [1] stated the vertical distribution of streamwise velocity could be separated into three layers: the upper non-vegetated layer, middle vegetation layer, and lower sheath layer.

In natural open channels, the flow condition is very complex, resulting in difficulties in understanding flow characteristics. Therefore, experimental tests and analysis are of great importance in vegetated channel studies.

It should be noted that, although there have been many studies on vegetated channel flow structures, there are few studies that focus on the double-layered, partially placed vegetated flow. The present study aims to present the experimental results of streamwise velocity profiles and their variations for double-layered, partially placed vegetated open-channel flow.

2. Methodology

2.1. Experiment Setup

The experiments were conducted in a straight flume at XJTLU (Xi'an Jiaotong-Liverpool University) hydraulic lab. The rectangular flume is 20m long by 0.4m wide with a bed slope of 0.003 (figure 1). Several fine-grid mesh boards are mounted at the entrance of the flume to distribute the flow uniformly. An adjustable tailgate at the downstream end is to maintain a constant water depth.

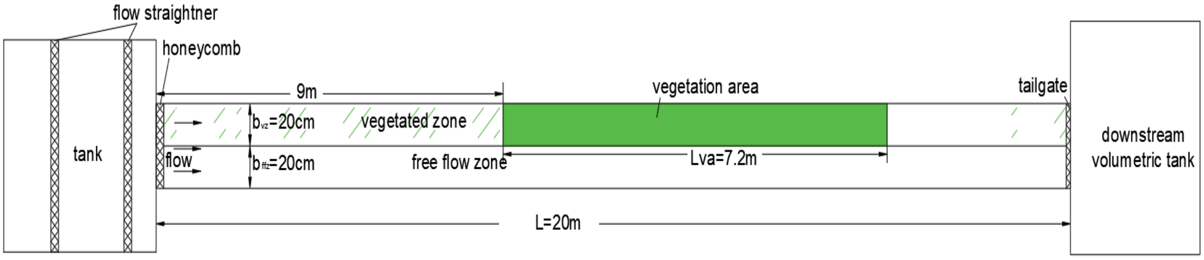

Figure 1. Top view of the experimental flume.

In this study, vegetation is restrained to a rigid plant and is simulated by two heights of dowels, with 10cm and 20cm dowels representing the short plant and tall plant, respectively. The diameter of all dowels is the same, i.e. D=6.35mm (where D is the dowel's diameter). PVC sheets with pre-perforated holes are used to hold the dowels.

The vegetation area is 7.2 m long, covering half of the channel bed on the left side, and was placed at 9m downstream from the channel entrance (see figure 1). Measuring points cover a whole cross-section of the channel, as shown in figure 2, where the black dots represent tall vegetation, the red star circles represent short vegetation, and the plus signs represent the measuring points. Velocity was measured by the propeller velocimeter at least twice for each measuring point, with a sampling time of 20 seconds for each point. The details of measuring positions are given in table 1.

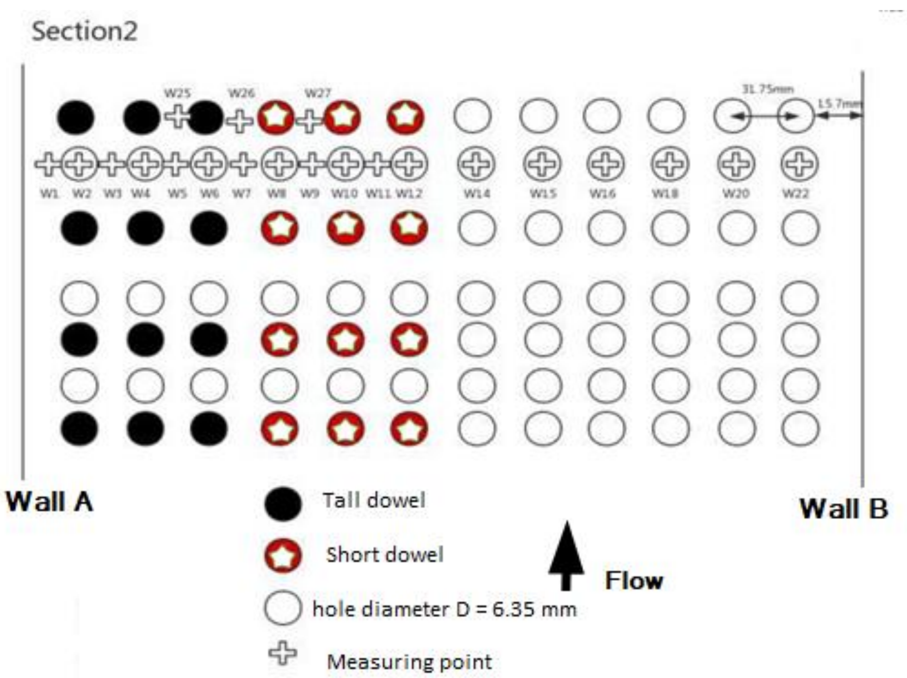

Figure 2. Vegetation arrangement and measuring points.

Table 1. The detail of measuring locations.

Vegetation Region		**Free Region**	
Measuring Point	Distance from Wall A (mm)	Measuring Point	Distance from Wall A (mm)
W1	12.7	W13	200.0
W2	25.4	W14	215.9
W3	41.3	W15	247.6
W4	57.1	W16	279.4
W5	73.0	W17	295.3
W6	88.9	W18	311.1
W7	104.8	W19	327.0
W8	120.6	W20	342.9
W9	136.5	W21	358.8
W10	152.4	W22	374.6
W11	168.3	W23	387.3
W12	184.1		
W25	73.0		
W26	104.8		
W27	136.5		

3. Results and Discussion

3.1. Streamwise Velocity Profiles

According to the vegetation submerged ratio, the velocity profiles in various experimental conditions are categorized into three groups: fully-submerged, half-submerged, and fully-emergent. Typical water depths of 9cm, 18cm and 22cm are selected to compare the overall change of velocity profiles (figures 3-5). To better understand the velocity profiles, dimensionless parameters are used herein. The vertical distance (z) from the bed is normalized by the short dowel height h_{vs} (i.e.10cm). The velocity is normalized by the friction velocity $u_*(=\sqrt{ghs_0})$, where g is the gravitational acceleration, h is the water depth and s_0 is the bed slope.

Typically, the streamwise velocity in the vegetated zone (w3 to w12) is much smaller than that in the free flow zone (w13-w22) in figure 3, which shows prominent resistance force exerted by vegetation. For submerged cases in figures 4 & 5, the vertical gradient of velocity near the short vegetation edge ($z/h_{vs}=1$) changes rapidly (w7 to w12), indicating strong momentum exchange in this layer. The vegetation will also affect the velocity profile in the free region (w14 to w22), showing a maximum value at about z/h_{vs} = 1.2 (partially submerged case) and 1.5 (fully submerged case). Besides, the velocities close to the bed (up to z/h_{vs} = 0.5) in the vegetated zone are almost constant, indicating a constant flow near the channel bed, where the flow is dominated by the drag of vegetation, as also pointed in [11].

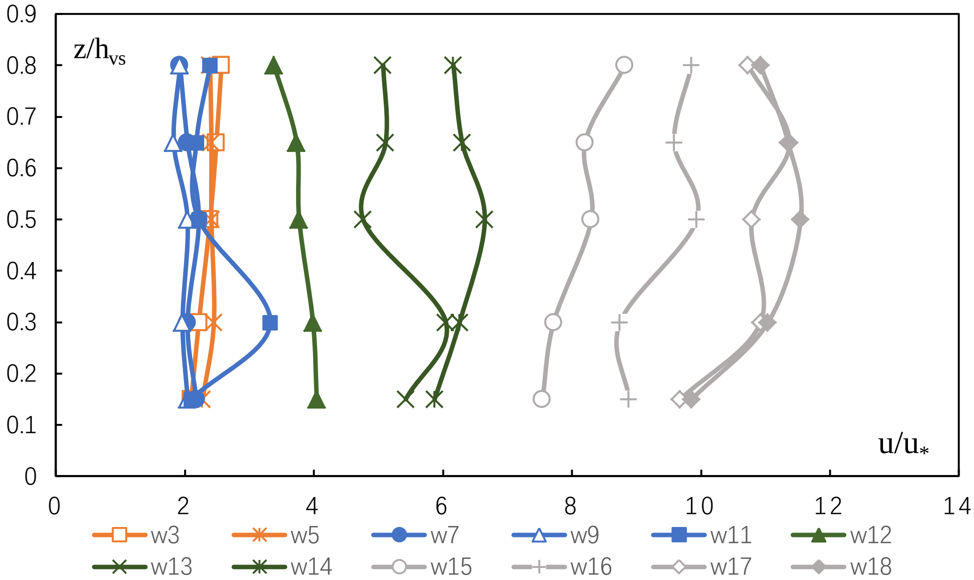

Figure 3. Streamwise velocity profiles when H = 9 cm (emergent case).

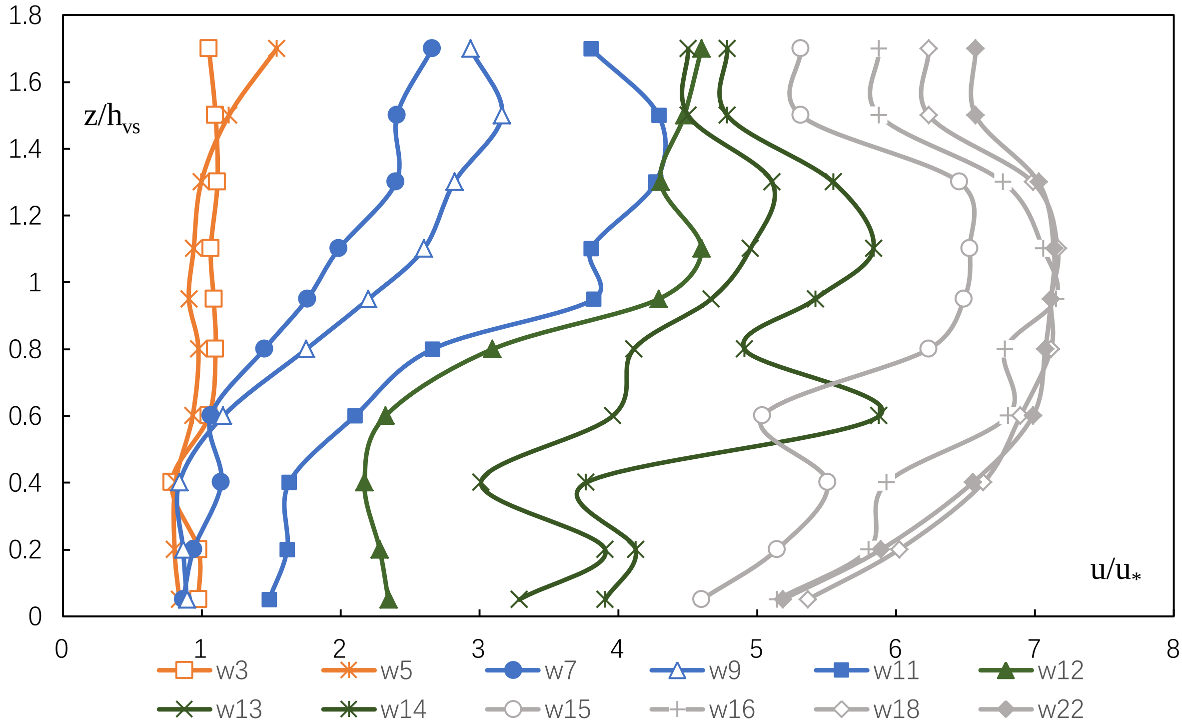

Figure 4. Streamwise velocity profiles when H = 18cm (partially submerged case).

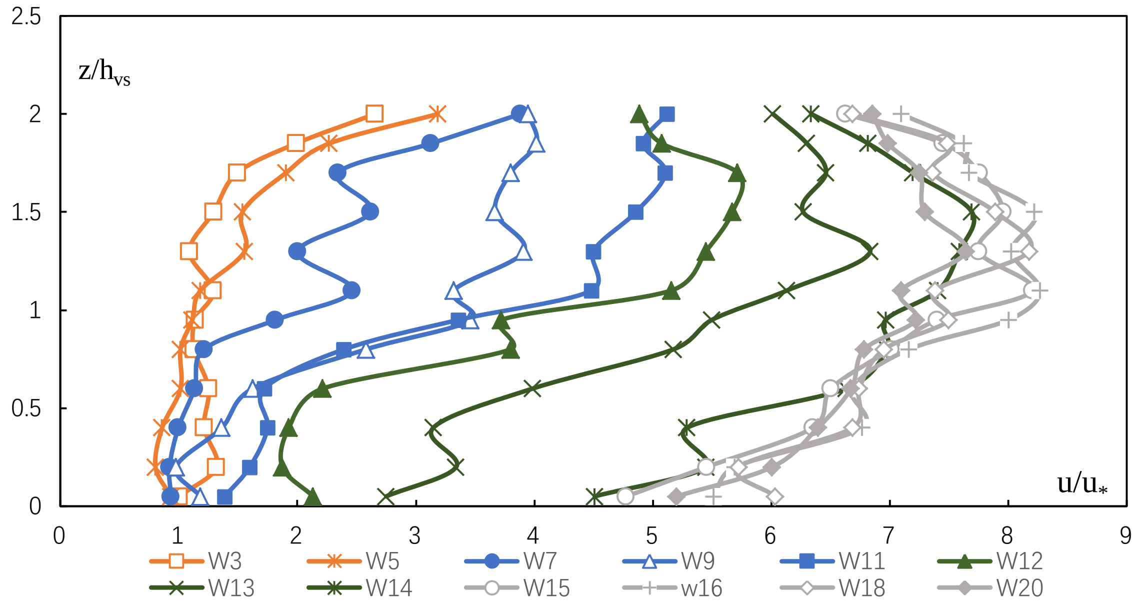

Figure 5. Streamwise velocity profiles when H = 22 cm (fully submerged case).

3.2. Lateral Variation of Streamwise Velocity

To understand the vegetation effect on flow, velocities along a cross section (i.e., at different locations such as between short vegetation, between tall vegetation, and in the free flow zone) are selected to compare. Herein, four typical vertical positions at z/h_{vs} = 0.2, 0.8, 1.1, 1.7 are chosen accordingly for all three depths (H=9cm, 18cm, and 22cm).

For the emergent case (figure 6), the velocity has little variation within the vegetation zone. However, the velocity starts to increase steadily from y =170 mm to a maximum at about y = 310 mm in the free flow zone, which appears that the velocity gradient increases as closing the top of short vegetation (z/h_{vs} =1). This result implies that a strong momentum exchange exists between the vegetation and free flow zones.

For the half submerged case (figure 7), the lateral distribution of velocity shows that the flow exchange significantly exists in the two transitions between the tall and short vegetation zone (90<y<152 mm), and the short vegetation and the free flow zone (152<y<250 mm). It also shows that the effect of vegetation on the change rate of velocity in the transition layer increases as increasing z/h_{vs}, especially the most significant change occurs near the top of short vegetation (e.g., z/h_{vs} = 1.1). Besides, the vegetation appears to affect a limited range of the free flow zone (up to y=250mm), i.e., velocity is not influenced at the far side near wall B.

For the fully submerged case (figure 8), similar to the partially submerged case, there exist two distinct transition layers, but the transition layer between the short vegetation and free zone is weakened, i.e., less lateral velocity gradient. This may be due to the weak effect of vegetation as increasing submergence. Moreover, the maximum velocity appears around the middle of the free zone.

Finally, the lateral velocity distribution at z/h_{vs} = 0.8 (near the top of short vegetation) for all three flow depths are compared in figure 9, which shows that the flow depth or submergence has less impact velocities on the vegetation zone than in the transition layer and free flow zones. Generally, the velocity gradient in the transition increases as smaller submergence. A maximum velocity occurs near the middle of the free zone only in emergent (or expected low submergence) conditions, but it does not occur when the submergence is high, see H= 18cm and 22 cm cases (i.e. H/h_{vs} = 1.8, 2.2 respectively). This result implies that the low submergence of vegetation should be considered in practical applications because it influences the lateral distribution of velocity, particularly in the transition layer between the vegetation and free flow zone.

4. Conclusions

This novel experimental study shows that vegetation has a significant retarding impact on flow velocity, especially under shallow water conditions. The vegetation existence in the part of a channel will create a distinct transition layer between tall and short vegetation and between vegetation and free flow zones. The lateral velocity gradient in the transition layer will be weakened as the increasing submergence ratio, which, however, has little effect on the emergent zone of vegetation. Furthermore, in the area near the top edge of the short vegetation, the velocity begins to increase and then grows significantly to the free surface through the tall vegetation height. The velocities behind the dowels are considerably lower than those in the free zone adjacent to the short and tall vegetation.

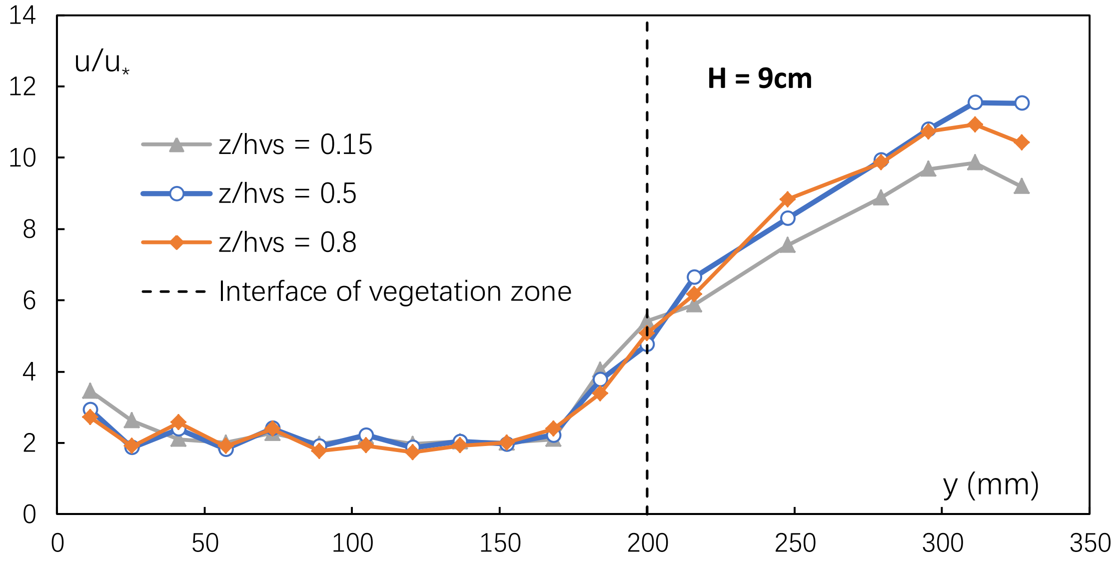

Figure 6. Lateral variation of streamwise velocity for H=9 cm (emergent case).

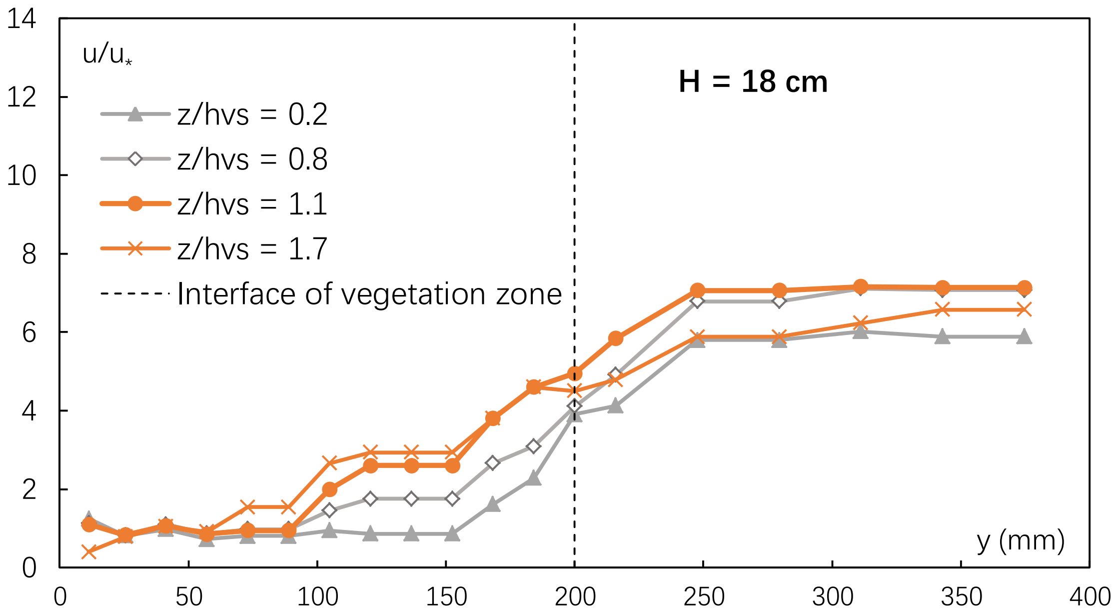

Figure 7. Lateral variation of streamwise velocity for H=18 cm (partially submerged case).

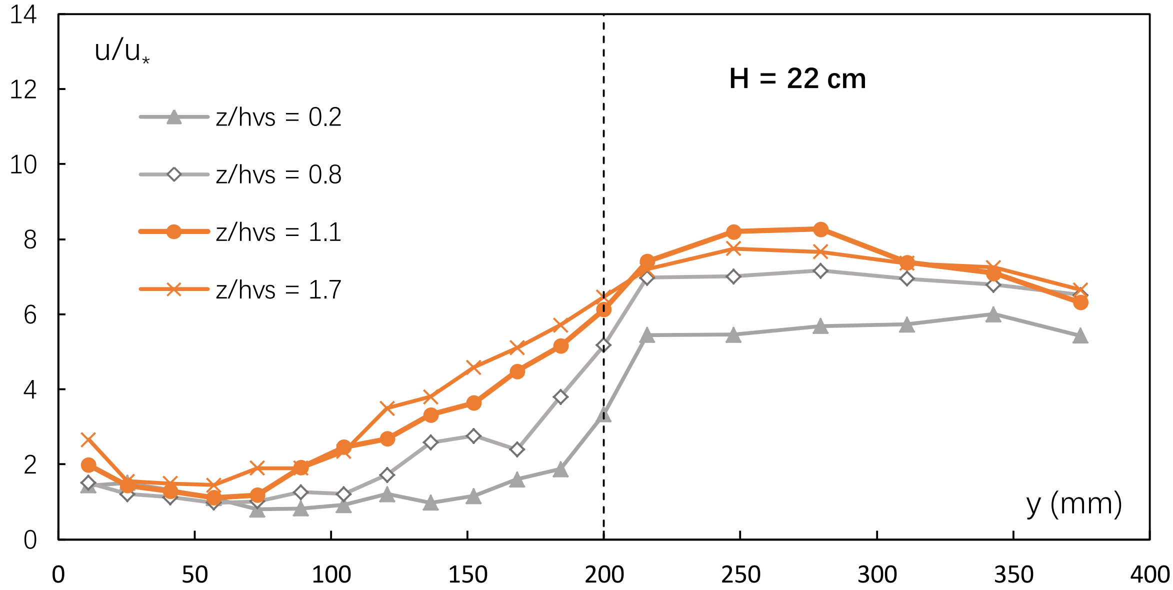

Figure 8. Lateral variation of streamwise velocity for H=22 cm (full submerged case).

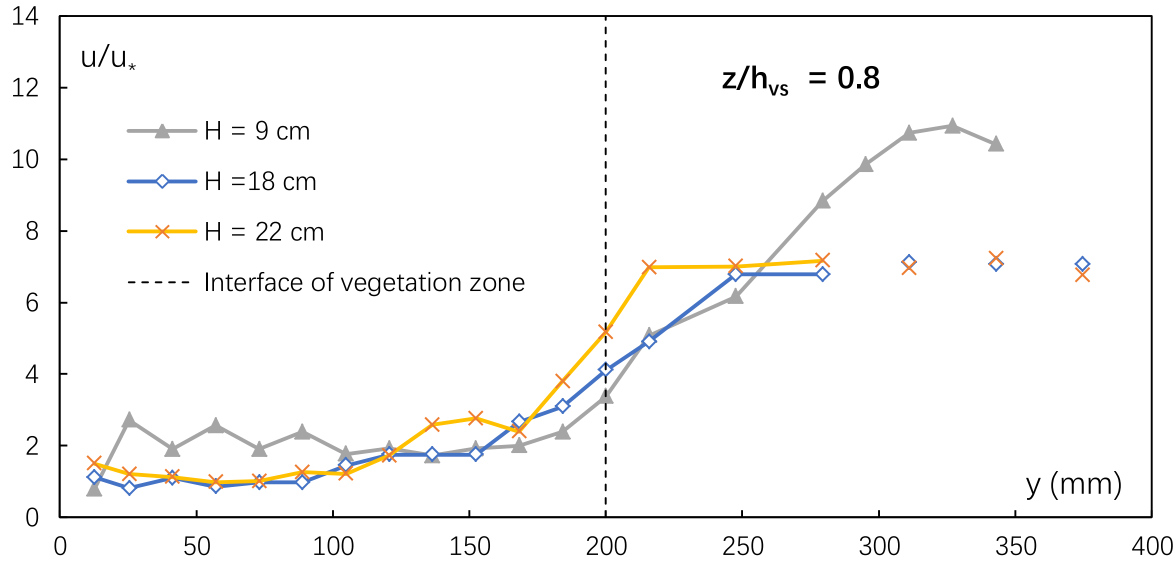

Figure 9. Comparison of streamwise velocity at the same z/h_{vs} = 0.8 for various water depths.

Acknowledgements
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