Hydraulic and Civil Engineering Technology VII
M. Yang et al. (Eds.)

doi:10.3233/ATDE220956

Influence of Partially-Covered Riparian Vegetation on Flow in a Compound Channel

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Abstract. Vegetation is of great importance in hydraulic engineering as it can affect the flow structures of compound channels in many ways, including the velocity profiles, momentum exchange, and shear stress distributions. This complex flow structure in vegetated compound channels has attracted more and more research interests. However, most of the previous studies have been focusing on fully-covered vegetated compound channels, there are little studies on compound channels with partially vegetated floodplain. This research carried out novel experiments to investigate the flow structure of compound channels with partially-covered vegetation on the floodplain. The results showed that the discharge of the main channel decreases as the depth ratio increases. The retardation effect of vegetation on the flow of non-vegetated floodplain region decreases with the increasing water depth. In addition, the vertical velocity profile in the vegetated zone performs differently in various depth ratios, with its velocity taking a maximum around the middle-water depth zone under emergent cases, while being the maximum near the free surface under submerged cases.

Keywords. Vegetated compound channels, flow velocity, vegetation resistance

1. Introduction

Compound channels are widely found in natural environmental settings, consisting of the main channel adjoined with one or two floodplains. Floodplains often sustain habitats for many kinds of vegetation, where trees or bushes are commonly observed along the edge of the floodplain (see figure 1) [1,2]. In recent decades, more and more researchers have been taking interest in the impacts of vegetated floodplains on the whole flow structure of compound channels [2-5]. Flow in vegetated compound channels differs from that in non-vegetated compound channels because the vegetation provides extra resistance force and increases the velocity gradient, resulting in slower flow velocity in the vegetated zone and intense momentum exchange at the interface [6]. In this way, it brings questions to the hydraulic field, such as river bank protection, flood alleviation, sediment transportation, and contaminants dispersion [7]. Therefore, understanding the flow characteristics of compound channels with vegetated floodplains is of great importance in solving practical engineering problems.

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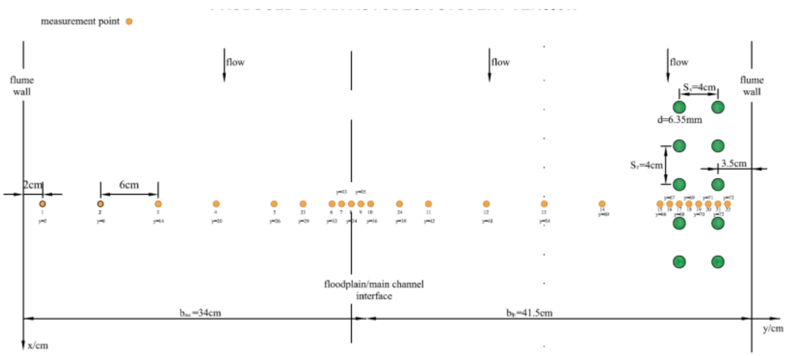
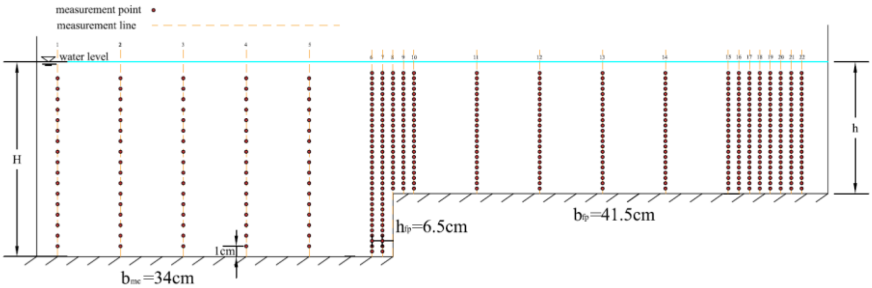
Figure 1. Riparian trees grown on the compound channel at the River Nene in England [2].

2. Experiment

Novel experiments were designed to study the flow structure in vegetated compound channels. The experiments were performed in a 75.5cm-width tilting flume of the Hydraulics Laboratory at the Xi'an-Jiaotong Liverpool University. The top and side views of the experimental setup are given in figure 2, where the green dots denote the vegetation. In this experiment, the plants were simulated by rigid dowels, with a height of 4cm and a diameter of 6.35mm. The dowels were firmly installed into a perforated board, with a displacement of 4cm between each other, and arranged as two lines of vegetation along the floodplain sidewall (see figure 2(a)). The bed slope was set as 0.003. The velocity components were measured using a 3D Nortek Acoustic Doppler Velocity meter (ADV). The measurement locations are shown in figure 2(a), where the orange dots denote the lateral measurement positions. The vertical measurement points were selected from 1cm above the bed with 0.5cm interval increment, denoted by the red dots on the orange lines in figure 2(b). The experiment conditions are summarized in table 1.



(a)



(b)

Figure 2. (a) Vegetation arrangement in a plan view and (b) measurement points.

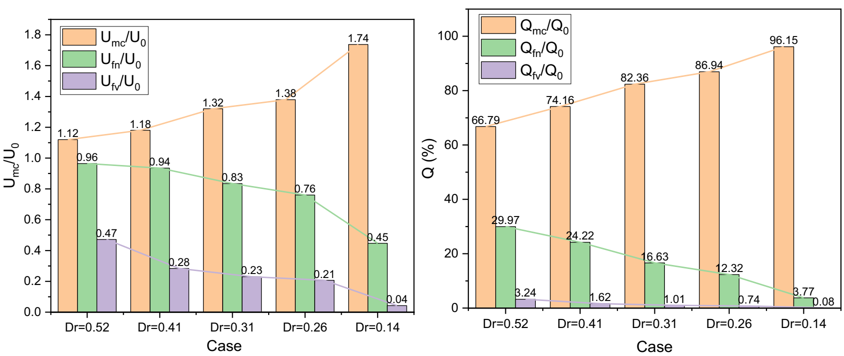
Table 1. Scheme conditions.

Case No.	Floodplain width b_{fp} (cm)	Flow rate Q_0 (L/s)	Water depth H (cm)	Depth ratio Dr (h/H)
1		14.23	7.6	0.14
2		17.93	8.8	0.26
3	41.5	22.06	9.6	0.32
4		23.55	11	0.41
5		36.8	13.6	0.52

3. Results and Discussion

3.1. Zonal Velocity and Discharge

For the vegetated compound channel, the whole channel can be categorized into three zones, i.e., the free-flow zone in the main channel (mc), the free-flow zone of the floodplain (fz) and the vegetated zone of the floodplain (fv).



(a) (b)

Figure 3. (a) The dimensionless zonal velocity and (b) The ratio of the zonal discharge to the total discharge in percentage.

The calculated zonal velocity is summarized in table 2. In figure 3, the zonal velocity U is normalized by the total-section mean velocity U_0, and the zonal discharge Q is normalized by the total discharge Q_0. From figure 3(a), it is evident that the mean velocity U in the main channel decreases as the depth ratio Dr increases, while the U on the floodplain increases as the Dr increases. The dimensionless zonal discharge shows a similar trend, indicating that the main channel's discharge decreases as the depth ratio increases.

Table 2. Zonal velocity U and Darcy-Weisbach's f.

Case	H cm	U_{mc} cm/s	U_{fn} cm/s	U_{fv} cm/s	U cm/s	f_{mc}	f_{fn}	f_{fv}
Dr=0.52	13.57	53.27	45.88	22.45	47.56	0.06	0.06	0.11
Dr=0.41	11.06	46.45	36.79	11.16	39.34	0.07	0.06	0.39
Dr=0.32	9.55	55.97	35.38	9.75	42.39	0.05	0.05	0.42
Dr=0.26	8.75	52.41	28.89	7.87	38.01	0.05	0.06	0.53
Dr=0.14	7.67	52.48	13.5	1.29	30.21	0.05	0.14	12.60

3.2. Vertical Velocity Profiles

One of the most crucial hydraulic features is the velocity profile. The understanding of vertical velocity profiles helps investigate the vertical flow structure. In this study, four specified locations are selected to show the vertical velocity distributions in the main channel (w3), in the free-flow zone on the floodplain (w12), behind the vegetation (w17), and in the gap behind the vegetation (w19).

The observed velocities in figure 4 showed that, in general, the flow in the main channel is faster than on the floodplain, so does the flow in the non-vegetated floodplain zone compared with that in the vegetated floodplain zone. Interestingly, the velocity behind the vegetation (w17) is larger than that in the gap behind the vegetation (w19). This is possible because the location of w17 is at the interface between the non-vegetated and vegetated regions, and thus this location was affected greatly by the large velocity of non-vegetated zone on the left side. In addition, the flow velocity in the non-vegetated floodplain zone is closer to the main channel velocity under a higher depth ratio, which indicates that the non-vegetated floodplain region is less affected by the vegetation resistance under higher depth ratio conditions. This finding is consistent with the higher Darcy's f in the vegetated zone under lower water depth, as explained in the next section.

In addition, as seen from figure 4, the vertical velocity profile of the main channel (w03) follows a 'J' curve, as the maximum streamwise velocity occurs at the middle zone under all depth ratios. Unlike that in the main channel, the points on the non-vegetated floodplain zone (see w12), the velocity reaches its maximum near the free surface under all depth ratios. However, for points in the vegetated zones, under submerged cases (Dr=0.52 and Dr=0.41, see figures 4(a) and 4(b)), the velocity reaches the maximum near the free surface, while under emergent cases (Dr=0.32 and 0.26, see figures 4(c) and 4(d)), the velocity reaches the maximum around the middle-water depth locations.

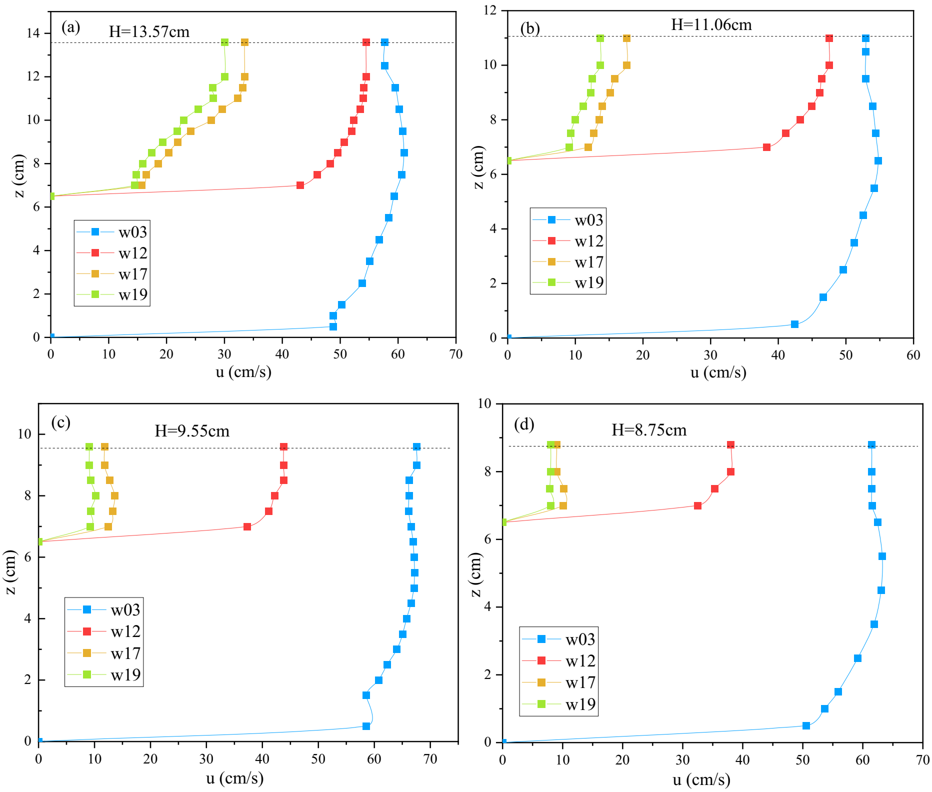


Figure 4. The vertical velocity distributions for cases: (a) Dr=0.52, (b) Dr=0.41, (c) Dr=0.32 and (d) Dr=0.26.

3.3. Darcy-Weisbach Friction Factor f

The Darcy-Weisbach's friction factor f is a common parameter representing flow resistance and could be used to calculate flow velocity and bed shear stress. Shiono and Knight [8] stated that f could be considered a constant in each zone, and thus the zonal f could be calculated by the zonal velocity [9], given by equation (1).

$$\mathrm{f} = \frac{8gRs}{U^2} \#(1)$$

where g is the gravitational acceleration; U is the zonal velocity; R is the hydraulic radius.

The results of computed U and f for each zone are summarized in table 2, in which the subscription mc indicates the main channel, fn indicates the non-vegetated region on the floodplain, and fv indicates the vegetated region on floodplain. Table 2 shows that the value of f in the vegetated zone is much bigger than in the free flow zones, which is consistent with the observation by Jumain et al. [10]. In addition, the f value in the main channel increases as the depth ratio Dr increases, while f in the vegetated zone decreases as Dr increases. The former observation could be explained by the increasing velocity in the main channel with the increasing Dr. The latter observation may be due to the smaller velocity under shallower water depth conditions. The increase of f_{fv} also indicates the increase of vegetation drag force as the depth ratio increases.

4. Conclusion

A series of novel experiments have been conducted to explore the vegetation impact on the compound channel flow structure. Zonal averaged velocity and discharge, vertical velocity profiles at specified locations, and regional Darcy-Weisbach's friction factor have been analyzed. The results showed that:

(1) The discharge ratio of the main channel to the total channel capacity is lower under higher water depth conditions.

(2) The retardation effect on flow resistance caused by the vegetation in the non-vegetated floodplain region is less obvious under a lower depth ratio.

(3) The Darcy-Weisbach's friction factor f in the vegetated zone decreases as the depth ratio increases while f in the main channel reduces with the increasing depth ratio.

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