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PIV Experimental Study on Flow Field near Lateral jet under the Condition of Vegetation

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Abstract. The high-frequency PIV was applied to measure the flow field near the lateral jet under the condition of rigid vegetation and flexible vegetation. Both the Single row vegetation and broadleaf grass were analyzed. The results showed that different vegetation arrangements have different effects on the jet flow field. The vegetation arrangement and vegetation resistance cause significant changes. The changes in flow velocity with changes in water depth displayed "S" type and anti-"S" type distributions, and the flow velocity of free layer was approximately logarithmic. Due to vegetation resistance and jet pressure differences, the lateral jet trajectory in water with vegetation also have different distributions. The lateral jet trajectory in water with broadleaf grass was more likely to bend than in water with rigid vegetation Compared to the influence of two vegetation arrangements on the water flow near the jet, the flexible vegetation has a better deceleration effect on the flow field near the lateral jet.

1. Introduction

Maintaining healthy rivers and promoting the sustainable use of water resources is an important issue for water resources managers and researchers. Plants not only directly affect the transport of sediment, pollutants, and nutrients in rivers, but they also facilitate the transportation of bedrock and suspended sediment in rivers. Plants also change the movement and diffusion of pollutants in a river. Under the action of water flow, plants will have a certain degree of bending deformation and fluctuation as a response to the water flow. Therefore, how to maximize the beneficial effects of aquatic vegetation on the river, while inhibiting its adverse effects, are essential to the ecological restoration and flood control of rivers.

A jet is a turbulent shear stream that plays an important role in crossflow. In terms of jet flow characteristics, a large number of studies were conducted by Fischer et al [1~5], showed that the axial velocity, concentration attenuation law, jet penetration height and jet trajectory equation. According to the different methods used by Fischer et al [6] or Metftah et al [7], the bottom jet was used to enter the open channel containing vegetation. Ben [8] analyzed the influence of emergent rigid vegetation on a jet going into an open channel. In the same way, Malcangio [9] showed that the effect rigid vegetation has on a circular whole floating jet, and with the decrease of the flow velocity in the crossflow, the penetration height and dilution of the jet increase significantly. Meftah [10] indicated that vertically dense jets within a crossflow, the flow field, jet trajectory, turbulence intensity, turbulent kinetic energy, turbulent length scale, and diffusion coefficient.

In order to study the interaction between the jet and vegetation from different angles, we focuses on two vegetation conditions: flow velocities, and the rest of this paper is organized as follows: Section 2 presents experimental facility and experimental conditions (such as the detailed laboratory flume measurements of the instantaneous velocity were obtained using a Particle image velocimeter (PIV). Section 3 presents an evaluation of the scheme's performance in two cases (the variation of the average flow-field distribution of a lateral jet in an open channel; the longitudinal jet flow velocity along a vertical line; the trajectory of a transverse jet; Section 4 provides the conclusions.

2. Experiment Equipment and Conditions

2.1. Sink Device

The experiment consists of a water supply device, steady flow device, test water tank, and water return device (as shown in Fig.1). The main channel is constructed of Plexiglas's; the coordinate system is defined by the center of the jet orifice as the coordinate origin.

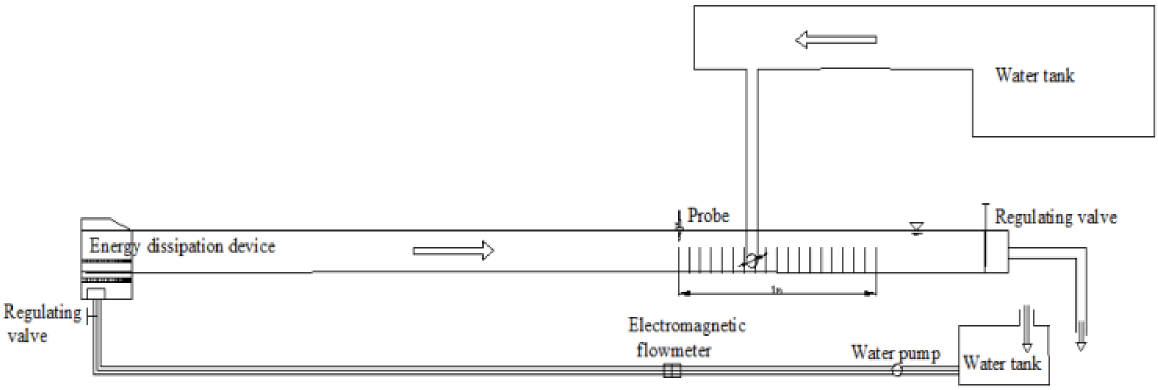


Figure 1. Sketch of the sink.

2.2. Experiment Equipment

Experiments were carried out in a smooth horizontal rectangular flume in the National Key Laboratory of Ecological and Water Conservancy of Northwest Arid Region of Xi'an University of Technology. The glass flume was 7.3 m long, 0.3 m wide and 0.25 m deep. In order to ensure the stability of the flow, a trash rack, a glass ball, and a floating row were arranged at the head of the sink. The side row jet hole was set at a distance of 2.6 m from the inlet of the water tank. The diameter of the jet hole was 0.01 m, which was represented with *D*, and it was installed at 0.1 m from the bottom of the water tank. Fig. 1 showed the experimental setup and coordinate system. The center of the jet orifice was considered to be the origin for the coordinate system. The *x*-axis was the streamwise direction, with $x = 0$ at the leading edge of the flume. The *y*-axis was the span wise direction and $y = 0$ was the edge of the flume. The *z*-axis was the vertical direction and $z = 0$ was the channel bed. The hollow glass sphere acts as the tracer particle D =10 μm.

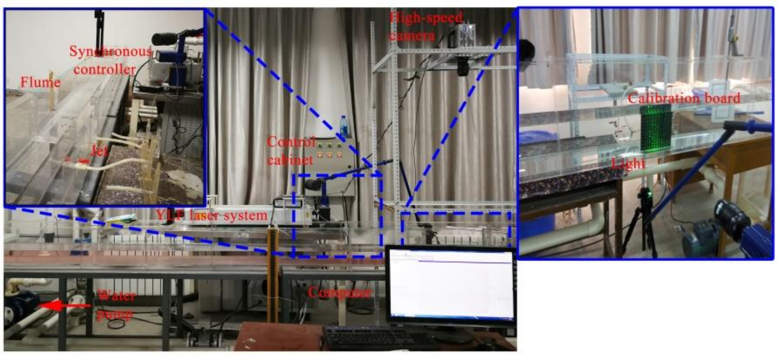


Figure 2. PIV measurement system and photo area

2.3. Experiment Conditions

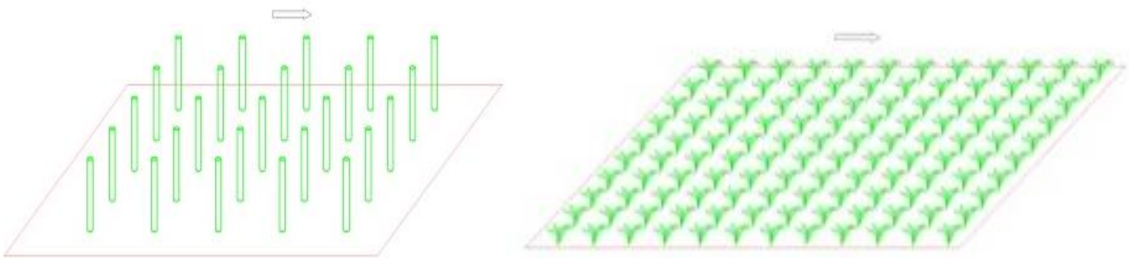
The initial parameters and experimental conditions were illustrated in Table 1. *H* was the ambient flow depth. *Re* was the Reynolds number for the jet. U_a was the main velocity. U_0 was the jet velocity. *R* was the velocity ratio. *X* was the lateral spacing, while *Y* was the vertical spacing.

Table 1. Parameters of the experiments

Run	condition	Q(m^3/h)	H(m)	Ua(m/s)	U_0(m/s)	R	Re	X (m)	Y (m)
V1J1	Single row	6	0.15	0.037	0.35	9.46	3500	0.03	0.02
V2J1	Broadleaf grass	6	0.15	0.037	0.35	9.46	3500	0.01	0.02

2.4. Vegetation Materials and Configuration

The transparent Plexiglas's rod was used to simulate rigid vegetation. The plant diameter was 8cm *and* the height was 10 cm. After inserting the place, the height is 9.2 cm. The Plexiglas's rod was fixed to a PVC board that was 100 cm long, 30 cm wide and 0.05 cm thick. The schematic diagram as follows.

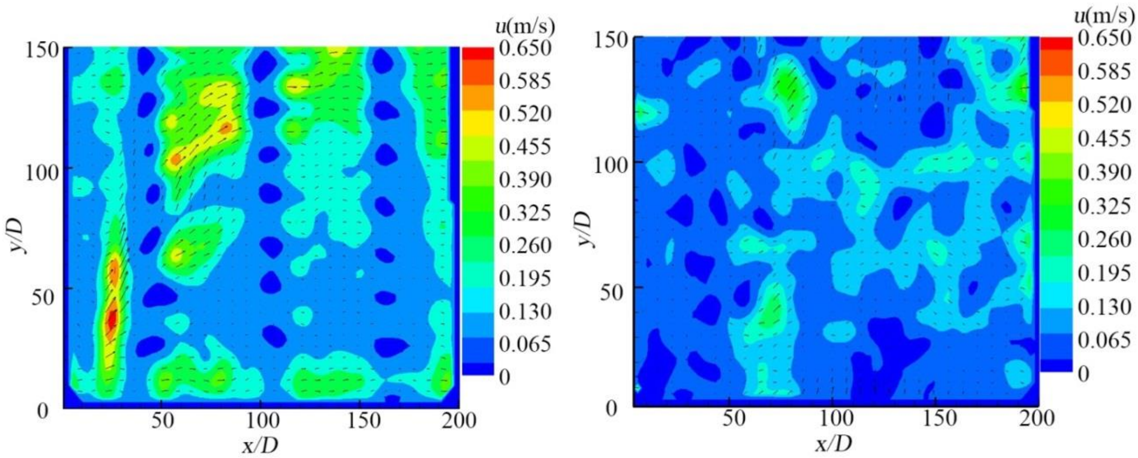


(a) Single row vegetation arrangement (b) Broadleaf grass arrangement.

Figure 3. Schematic diagram of vegetation arrangement

3. Results and Discussion

3.1. Distribution of Average Flow Field in a Transverse Jet under the Condition of Vegetation



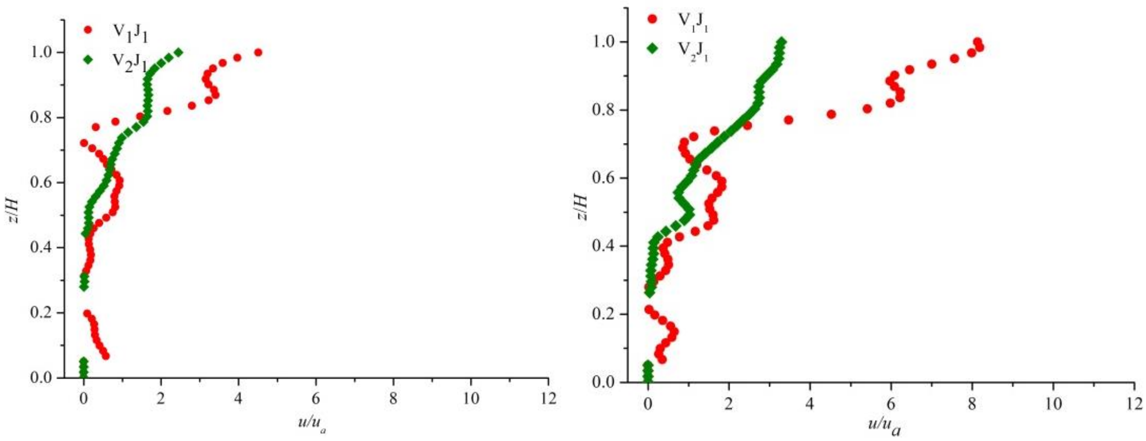
(a) vector map of u_{xz} for run V_1J_1 (b) vector map of u_{xz} for run V_2J_1

Figure 4. Time-average flow rate vector (z/D = 5)

Figure 4a showed that with single-row vegetation (V_1J_1), the maximum jet velocity of u_{max} = 0.065 m/s was reached at the jet nozzle. Due to the flow around the vegetation, after the jet passed through the vegetation area, the jet velocity drastically deceased. There was a reverse vortex of varying shapes and sizes, and the velocity approached zero. The velocity gradually increased after the jet passed beyond the vegetation. Figure 4b showed that with broadleaf grass (V_2J_1), the velocity of the flexible vegetation was more complicated. The velocity of the flexible vegetation was weaker than rigid vegetation.

3.2. Vertical Flow Velocity Distribution of a Transverse Jet along a Vertical Line with Vegetation

The average flow velocity distribution along the vertical line had obvious regional characteristics. To highlight the significant effects of a cylindrical array of vegetation on the jet flow, we compared some vertical profiles of the dimensionless velocity u/u_a between jets discharged into the rigid vegetation channels (V_1J_1) and into the flexible vegetation channels (V_2J_1) at different downstream positions x/D (seen Figure 5).



(a) Velocity distribution along the vertical at x/D = 50. (b) Velocity distribution along the vertical at x/D = 80.

Figure 5. Vertical flow velocity distribution of the lateral jet at the different positions *x/D* under different conditions.

In Figure 5, u/u_a represents the flow ratio and the ordinate z/H represents the water depth ratio. Figure 5a showed the water depth ratio of $z/H = 0$ to $z/H = 0.5$ for the V_1J_1 condition with a single row vegetation. The longitudinal velocity changed drastically in the vertical direction and the velocity distribution showed obvious S and anti-S types. For the V_2J_1 conditions, the longitudinal flow velocity was approximately linear. In summary, there were many factors affecting the velocity distribution, such as roughness, jet resistance coefficient, drag coefficient *Cd* and infiltration height.

3.3. Transverse Jet Motion Trajectory with Rigid vegetation and Flexible Vegetation

The jet trajectory, which was the jet entered the cross-flow, was an important parameter. Ben, Meftah [11] used the dimensionless *D* and the dimensionless r_jD to analyze jet trajectory changed. With vegetation and without vegetation, the study was conducted to analyze the changes in the transverse jet trajectory. To further analyze the jet trajectory, Kam[12] proposed an alternative scaling, normalizing the coordinates with *D* that was, *x*/*D* and *y*/*D*, and went on to obtain a power-law of the jet trajectories in the form of

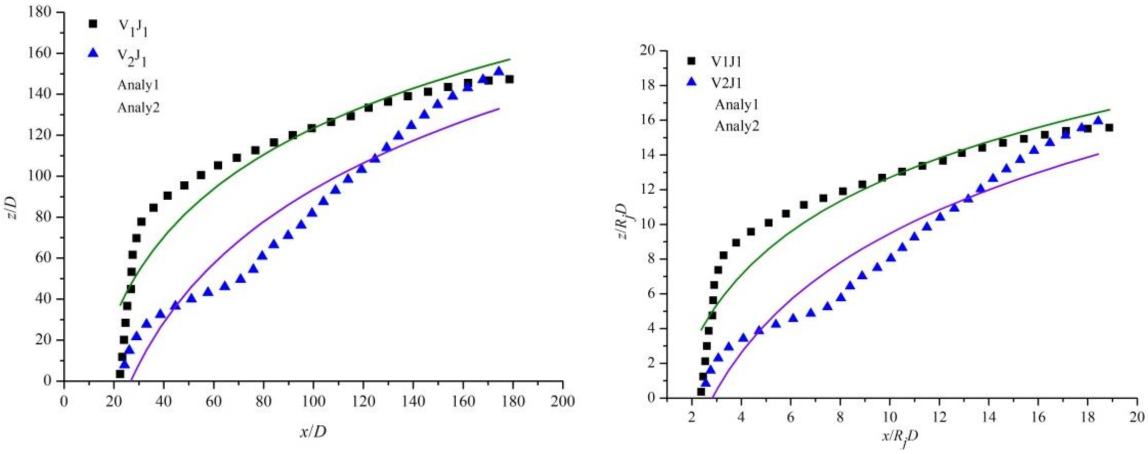
$$\frac{y}{D} = A\left(\frac{x}{D}\right)^B \tag{1}$$

In Equation (1), A and B were experimental coefficients. Margason[13] reviewed several correlations and concluded that much of the data could be collapsed by normalizing coordinates with the product r_jD, leading to a simple power-law trajectory in the form of

$$\frac{y}{r_j D} = A\left(\frac{x}{r_j D}\right)^B \tag{2}$$

A power-law similar to Equation (2) was also proposed by Pratte[14]. It was based on their dimensional analysis for a jet of $r_j D$ ranging from 5 to 35.New. [15]. Indicated that some researchers affirmed that the jet trajectories were best scaled with $r_j D$, instead of D or $r_j^2 D$.

Figure 6 showed the jet trajectories for different conditions. In Figure 6a, *x*/*D* represented the water flow ratio, and *y*/*D* represented the river width ratio. In Figure 6b, x/ $r_j D$ represented the water flow ratio, y/$r_j D$ represented the river width ratio, and r_j represented the ratio of the ambient flow rate to the jet flow rate. V_1J_1 represented the lateral jet trajectory with rigid vegetation, and V_2J_1 represented the lateral jet trajectories with flexible vegetation.



(a) Coordinates are normalized by *D* (b) Coordinates are normalized by $r_j D$

Figure 6. Jet axis motion trajectory

As shown in Figure 6a, by comparing the scatter points with the fitting curves of the jet trajectories under two conditions, it was found that different vegetation arrangements resulted in different curves of the jet trajectories. The curve of Analy1 fitted well with that of V_1J_1 under with single row vegetation. Under the effect of flexible vegetation, the trend of the jet trajectory curves was consistent and the fitting curves were also very similar. Under the action of flexible vegetation, the scatter points of V_2J_1 fluctuated greatly with the curve of Analy2.

4. Conclusion

The PIV flow rate measurement system can quickly, accurately, and effectively acquire the time-averaged and turbulent flow field characteristics near a lateral jet, and then has no interference to analyzing the flow field at a high resolution. The main conclusions are as follows:

According to the analysis of the vertical flow velocity, the flow velocity in the inner region of the vegetation and near the bottom of the trough was reduced. The flow velocity along the water depth was of S and anti-S types, by comparing the jet trajectories under different conditions, it was found that jet penetration was significantly greater. And the jet trajectory was more curved for the flexible vegetation arrangement.

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