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Deposition of fine particles in submerged vegetation patch in river flow

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Abstract. The submerged vegetation patch in river flow produces additional resistance through drag force and changes the bed shear stress of flow. Thereby it influences the deposition of fine particles including some kind of metal pollutants on flow bed. The relative height of vegetation patch imposes influence on the variation of bed shear stress, therefore it being expected to influence the deposition of fine particles as well. To investigate the influence of relative height of vegetation patch on deposition of fine particles in river flow, a set of indoor physical experiments with twelve relative heights were conducted in a straight water flume. The results show that for low relative heights, the deposition decreases with the increase of relative height. For medium relative heights, the deposition increases with the increase of relative height. For high relative heights, the deposition no longer varies with the increase of relative height. There are two main contrary effects accounting for this variation, the first one is the increased flow velocity due to the compassed cross-sectional area, which cause the bed shear stress increasing. The second effect is from the increasing drag force with the increasing submergence of vegetation patch, which causes the bed shear decreasing. The results of this study are expected to provide fundamental mechanisms for the removal of metal pollutant through vegetation patch in river flow.

1. Introduction

The submerged vegetation in river usually grows in patch, which plays important roles for the removal of pollutant, for the self-purification of water quality, and for the balance of aquatic eco-system (Kuriata-Potasznik et al., 2018; Branković et al., 2012; Madsen et al., 2001). The submerged vegetation patch exerts drag force, thus generating the primary resistance to flow. The presence of vegetation patch modifies the velocity profile within and above it. Correspondingly, the local bed shear stresses both in the vicinity of vegetation stem and in the middle point among stems will change. The changes in local bed shear stress will cause variations in deposition of fine particles, that is, they will enhance the deposition in the circumstance of decreased bed shear stress and reduce the deposition in the circumstance of increased bed shear stress.

The presence of submerged vegetation has two contrary effects on the bed shear stress. For one thing, the drag force of vegetation stems reduces the bulk flow velocity and therefore has a possible tend to reduce the bed shear stress. For another thing, the vegetation patch can increase the local flow velocity and the bed shear stress because it reduces the cross-sectional area of flow. The competing result of these two contrary effects is impacted by the relative height of the vegetation patch, therefore the net influence of vegetation patch on deposition of fine particles varying with the relative height.
The objective of this study is to investigate how the submerged vegetation patch influences the bed deposition of fine particles under various relative height conditions. A set of physical experiments were conducted in an indoor water flume. Twelve relative heights were set up to investigate the variation of total amount of deposition.

2. Experimental setup
The indoor experimental water flume was straight and the cross-section was rectangular. The size of the flume is 12 m long, 40 cm wide and 40 cm high (Fig. 1 and 2). The two side walls of the water flume compose of aluminum alloy frames with transparent glasses embedded. The glass windows allowed the observers to have convenient views when they set up the vegetation models and the measuring devices. A water tank with three dimensions of $1 \, \mathrm{m} \times 1 \, \mathrm{m} \times 0.6 \, \mathrm{m}$ was installed at a location 2.5 m ahead of and 1.5 m above the upstream end of the flume (Fig. 2). The water tank was connected to the water flume with an upper opening corridor. The connecting corridor is 25 cm wide and 45 cm high. The corridor was tilt at a degree of $31^\circ$. Thus the water head (1.5 m) between the tank and the flume provided enough energy for the experimental flow to obtain a designed discharge. The water level was maintained at a constant value by delivering water into it during each experimental test. Five sets of steel screen with sieve diameter of 2.5 mm were vertically installed at the entrance section of the flume to regulate flow (Fig. 1). A tail wire was set at the outflow wall of the flume to measure the discharge ($Q$). The bed slope of the flume was adjusted to 0.0065 to maintain the experimental flow in a steady and uniform state. The flow discharges ($Q$) were kept at a constant value of 16300 cm$^3$/s, and the flow depth ($H$) was 18 cm.

![Fig.1. Horizontal view of experimental setup](image1)

![Fig.2. Side view of experimental setup](image2)

The flow velocity was measured with ADV and the bed shear stress was evaluated from the velocity measured near bed. The submerged vegetation stem was modeled with rigid wooden cylinder...
of diameter 0.35 cm. Twelve vegetation heights were set at \( h_p = 1, 2, 3, 4, 6, 8, 10, 12, 13, 14, 15, \) and 16 cm. Thus it created twelve relative height \( h_p/H \) (summarized in table 1). The vegetation stems were fixed on the flow bed with steel nails. The vegetation patch was set in the middle section of the flume, occupying 6 m long and the full width of the flow bed. The vegetation stems were arranged in stagger pattern (Fig. 3). The spacing between two neighboring stems \( s = 1.53 \) cm for all the twelve experimental tests.

The fine particles were modeled with quartz sand of uniform diameter of 220 \( \mu m \). The specific gravity of the fine particles was 2.68. The fine metal particles were released from a vertically installed board at the upstream end of the flume. There is a nozzle on the particle releasing board to blow the fine particles out into the experimental flow (Fig. 2). The process of particle releasing lasted during each entire experimental test for 1 h. The bed deposited particles were collected and measured with thin square transparent acrylic plate with dimensions of 1.2 cm \( \times \) 1.2 cm. Fifteen particle collecting plates were put on the middle section of the vegetation patch (Fig. 1). These fifteen plates were arranged in 3 columns and 5 lines. They were taken out after the experimental flow stopped and were dried in an oven.

| Experiment No. | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 |
|---------------|---|---|---|---|---|---|---|---|---|----|----|----|
| \( h_p/cm \)  | 1 | 2 | 3 | 4 | 6 | 8 | 10| 12| 13| 14 | 15 | 16 |
| \( h_p/H \)   | 0.06 | 0.11 | 0.17 | 0.22 | 0.33 | 0.44 | 0.55 | 0.66 | 0.72 | 0.78 | 0.83 | 0.89 |

3. Results
The total amount of deposited fine particles collected by the fifteen square plates was presented by the mass \( m_d \) (g). The relative height of vegetation patch was defined as the height of vegetation patch and water depth \( (h_p/H) \). For the eight relative heights, the relationship of \( m_d \) and \( h_p/H \) was plotted in Fig. 4. It shows that \( m_d \) decreases with \( h_p/H \) at low relative height when \( h_p/H \leq 1/6 \); for medium relative height \( 1/6 < h_p/H \leq 2/3 \), \( m_d \) increases with \( h_p/H \); and for high relative height when \( h_p/H > 2/3 \), \( m_d \) does not vary with \( h_p/H \) any more.
Fig. 4. Variation of $m_d$ with $h_p/H$

The reason account for this variation trend is that for low relative height when $h_p/H \leq 1/6$, the cross-sectional area in the low part of water depth, i.e., the vegetated partition of the water column is compassed due to the presence of the vegetation patch. Therefore the flow velocity among the vegetation stems and the bed shear stress are increased, which cause the fine particles less deposited. For the medium relative height when $1/6 < h_p/H \leq 2/3$, the form drag exerted by the vegetation patch predominates, which causes the flow velocity and the bed shear stress decreased, thereby the deposition increasing. For high relative height when $h_p/H > 2/3$, although the drag force increases and the bulk flow velocity is reduced, their influence on the bed shear stress in negligible small. Consequently, the deposition no longer increases.

4. Conclusions
The relative height of vegetation patch in river flow influences the flow velocity, bed shear stress and the deposition of fine particles on bed. The mechanism of this influence are based on two contrary effects, the first one is the increased flow velocity due to the compassed cross-sectional area, which cause the bed shear stress increasing, thereby less deposition occurring. The second effect is the increasing drag force with the increasing relative height, which causes the bed shear decreasing, thereby more deposition occurring.

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