Hydraulic Characteristics of Microbend River with Vegetation on the Slope

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Abstract. The flow pattern of the water with vegetation is complex. For the micro-bend channel which has compound cross-sections and has vegetation on the slope, the situation is more complex. This paper measures and analyses the hydraulic characteristics of the micro-bend channel with trapezoidal cross-sections and with vegetation on the slope, by using the ACM2-RS electromagnetic flow meter. The influence of vegetation structure changes on the hydraulic characteristics are further analysed, which includes flow velocity distribution, turbulence intensity and channel roughness. Studies have shown that, with the decrease of the rigidity of vegetation density, the sinuosity of the hydrodynamic axis increases, the longitudinal velocity of each section in the main channel has an obvious trend of decrease. Besides, the longitudinal and lateral turbulence intensity keeps constant in the main channel, have obvious decreasing trends on the slopes. In addition, river manning roughness coefficient increases with the increase of rigid vegetation density.

1 Introduction

Natural river is a complex dynamic system, which contains not only inanimate substances, such as water flow, nutrients, sediment, etc., but also biological components. Plants in river course or riverside are the basic elements of river dynamic system. Curved river is one of the most common alluvial river patterns, which has many different flow characteristics from straight river. Compound cross-section is composed of main channel and flood plain, which is common in plain rivers and coastal rivers. It is of great significance for the sustainable utilization of water resources and the ecological protection of water environment to study the flow structure and mechanism of vegetation micro bend river channel with compound sections. At present, the research on the flow structure, turbulence characteristics and resistance characteristics of the river with vegetation has achieved rich achievements. In terms of the impact of vegetation on water flow structure, Li et al. [1] studied the influence of tree density and arrangement on flow velocity in rectangular channel by simulating vegetation with cylinder. Fathi-Maghadam and Kouwen [2] studied the qualitative relationship among flow resistance, flow parameters and plant parameters of flow with flexibility and not submerged vegetation under the condition of slow flow or fully developed turbulent flow. Wang et al. [3] calculated the flow field of Nansi Lake by using the two-dimensional water depth average hydrodynamic mathematical model, and found that the non-submerged aquatic plants (reed) and submerged plants have a great influence on the flow field. In terms of the influence of plants on the turbulent characteristics of water flow.
Nezu and Onitsuka [4] studied the turbulent characteristics of rigid plants in a glass flume with variable slope and compared with those of non-plants. Some studies have focused on flow resistance. Kouwen et al. [5-6] carried out an experimental study on the flow resistance of flexible plants in open channels. Järvälä [7] studied the typical low-speed flow and flood flow structure with grass and shrub in wetland and floodplain in the flume, in order to study the resistance coefficient of flow in natural floodplain and wetland. Shi and Hughes [8] discussed the variation law of velocity, friction velocity, rough Reynolds number and boundary shear stress in the test flume, and the influence of plants on the laminar boundary layer. However, there are few achievements in the study of micro bend channel with small sinuosity coefficient. In addition, a large number of studies on the compound cross-section flow are mainly focused on the core area of the flow, that is the main channel. While there are few studies on the velocity and turbulence intensity of the beach. In this paper, the influence of vegetation density changes on the river flow velocity, turbulence intensity and roughness are studied by the indoor flume experiment. The research results can not only reveal the river bed evolution law under the condition of changing flow characteristics, but also provide the basis for river management and ecological restoration.

2 Experiment

The test flume is 15m long, 1m wide, 0.5m deep, and the longitudinal bottom slope is 0.5 ‰. The test model adopts generalized curve model, with smooth cement wall on both sides and smooth cement floor at the bottom. The test equipment mainly includes: the flume, submersible pump, water reservoir, tail gate, tail reservoir, return channel, etc. The layout of the test flume and return water system is can be seen in Figure 1.

![Figure 1. The layout of the test flume and return water system](image)

Constant and uniform flow conditions are adopted for the experiment, with fixed flow discharge and tail water level. The flow discharge is 12L/s, and the tail water depth is 12cm. Considering the water surface gradient of the whole test flume is small, the bend part of the test flume is basically at the bankfull water stage.

The bend part of the test flume is 8m long, consisting of four complete cycle curves. The radius of the curve centerline is 0.86m, and the curve curvature coefficient is 1.07. The velocity and water level measurement sections are mainly arranged in two complete cycle bends, from cs1# to cs8#, as can be seen in Figure 2. The test flume is in the range of 0 to 1m in the vertical axis, and the dotted line in the figure is the boundary between the slope and the main channel. Figure 3 show three typical sections of the bend, concave bank on the left bank, convex bank on the left bank, and the transition section.
The water level in the experiment is measured by the LH-1 automatic water level meter developed by the Wuhan University, as shown in Figure 4. The flow rate is measured by ACM2-RS electromagnetic current meter developed by JFE company of Japan, as shown in Figure 5. The electromagnetic current meter is 2-dimensional, and in X-Y direction.

In the experiment, 12# cylinder iron wires were used to simulate the trees on the slope of the river. The diameter of the iron wire is 2.6mm, and the length is 7cm. The buried depth of wire is 2cm, and the exposed length is 5cm. The rigid vegetation is arranged in the range of 3.5m to 8m in the flume. Table 1 shows the vegetation density of five cases of the experiment.
Table 1. The vegetation density in each case

| Case | Interval in the x direction/cm | Interval in the y direction/cm | Density /(strain/m²) |
|------|--------------------------------|--------------------------------|----------------------|
| 1    | 5                              | 2                              | 1000                 |
| 2    | 5                              | 4                              | 500                  |
| 3    | 5                              | 6                              | 333                  |
| 4    | 10                             | 4                              | 250                  |
| 5    | 10                             | 8                              | 125                  |

3 Results and discussion
In the test, 14 vertical lines are taken equidistant from the left bank to the right bank on each section. The interval between the measuring points in the vertical line is 1cm, and the vertical velocity is measured 2cm below the water surface, due to the limitation of the instrument. 96 measuring points are arranged for each section, and nearly 800 measuring points are arranged for one case. The density of measuring points can basically reflect the flow structure.

3.1 Changing law of the flow dynamic axis
The changing law of the flow dynamic axis of the curved river is an important feature of the flow movement. It directly shows the change of the maximum vertical average velocity along the river, and also reflects the change process of the main flow along the river. According to the general law of velocity distribution in continuous bend, the velocity is larger near the convex bank and smaller at the concave bank in the apex of the bend. The velocity distribution of cross section at one apex is transversely symmetrical with that at the downstream apex, and the velocity gradually transits between the two bends apex.

Figure 6 shows the flow field and main flow line in the micro bend channel of different cases. The main flow line has been marked with thick line. It can be seen from the figure that, the cross-section velocity distribution at the top of two consecutive bends does not show transverse symmetry. That is to say the transverse symmetry has been deformed due to the existence of vegetation. This kind of deformation is not obvious as the density is large. However, the deformation is relatively significant as the density is small. Moreover, the twist degree of the hydrodynamic axis is increased, and the mainstream line is more inclined to the convex bank, even appears on the slope of the convex bank at the apex of the bend.
3.2 Changing law of the longitudinal vertical average velocity

Figure 7 shows the comparison of longitudinal vertical average velocity under 5 groups of different vegetation density in each section. The vertical line in the figure represents the boundary between the main channel and the slope. It can be seen that the longitudinal velocity of the main channel in each section has a significant trend of increase with the increase of vegetation density. Taking the 7th vertical line of section 4 as an example, the average velocity of vertical line is 30.1cm/s, 31.9cm/s, 33.2cm/s, 34.1cm/s and 35.9cm/s, as the density is 125 strain/m², 250 strain/m², 333 strain/m², 500 strain/m² and 1000 strain/m² respectively. However, the longitudinal velocity distribution on the slope, especially near the bank, is disordered, and there is no obvious trend change.
Figure 7. The comparison of longitudinal vertical average velocity in each section between different cases

3.3 Changing law of the transverse velocity distribution

Because the transverse circulation is concentrated in the curved section, the transverse velocity in the vertical line near the convex bank in the main channel of each curved section is selected for comparison. Figure 8~Figure 9 show the vertical distribution of transverse velocity in the main channel of each curved apex section. The transverse velocity is positive from the left bank to the right bank.

It can be seen from the figure that the transverse velocity of each section is far less than the longitudinal flow. In addition, the transverse velocity of CS2# and CS6# near the water surface is positive, from convex bank to concave bank, and the velocity distribution is in the shape of "<". The transverse velocity near the bottom of the trough is negative, from concave bank to convex bank. The transverse velocity of CS4# and CS8# near the water surface is negative, from convex bank to concave bank, the velocity distribution is in the shape of ">". The transverse velocity near the bottom of the trough is positive, from concave bank to convex bank. The results show that, for the micro bend river with vegetation on the slope, the surface flow direction from convex bank to concave bank, the bottom flow direction from concave bank to convex bank.

Figure 8. The vertical distribution of transverse velocity on the vertical line with y/b=0.35
Figure 9. The vertical distribution of transverse velocity on the vertical line with y/b=0.65

3.4 Changing law of the turbulence characteristics

Fluctuating velocity is one of the most important characteristics of flow turbulence. Figure 10–Figure 12 show the vertical distribution of longitudinal turbulence intensity in the main channel or on the slope for each section, three groups of vegetation density are selected.

As it can be seen from Figure 10, the longitudinal turbulence intensity in the main channel of the bend is between 0 to 9.2cm/s. The turbulence intensity near the surface is large, and it decreases to an approximate fixed value with the increase of the water depth. There is a slight increase in the area near the bottom, and it approaches to zero near the bottom. In addition, the values of transverse turbulence intensity and longitudinal turbulence intensity are similar, and the distribution law is basically the same. In terms of different vegetation density, the turbulence intensity of the main channel is basically unchanged with the change of vegetation density of the slope.

As it can be seen from Figure 11–Figure 12, the turbulence intensity on the slope is obviously smaller than that of the main channel in the same depth of water. The turbulence intensity near the surface is large, and it decreases to an approximate fixed value with the increase of the water depth. Besides, it approaches to zero near the bottom. The distribution law of transverse and longitudinal turbulence intensity is similar, but there are obvious differences in distribution. In terms of different vegetation density, the turbulence intensity of slope has a significant decreasing trend with the decrease of vegetation density.
**Figure 10.** The vertical distribution of longitudinal and transverse turbulence intensity on the vertical line with y/b=0.47 for each cross-section

**Figure 11.** The vertical distribution of longitudinal and transverse turbulence intensity on the vertical line with y/b=0.24 for each cross-section
Figure 12. The vertical distribution of longitudinal and transverse turbulence intensity on the vertical line with \( y/b = 0.76 \) for each cross-section

3.5 Changing law of the coefficient of roughness

The coefficient of roughness is approximately obtained by using Chezy formula and Manning formula. Figure 13 shows the calculated value and fitting curve of roughness coefficient with the change of vegetation density. It can be seen that, the roughness increases with the increase of the rigid vegetation density of the slope, and the corresponding roughness coefficient changes between 0.034 to 0.045, as the vegetation density in this experiment is ranged from 0 to 1000 strain/m².

Figure 13. The calculated value and fitting curve of roughness coefficient with the change of vegetation density

4 Conclusions

In this paper, the effects of vegetation density changes on the hydrodynamic axis, vertical average velocity, transverse velocity distribution, turbulence characteristics and Manning roughness of river channel are studied, by using iron wires to simulate the trees on the ecological boundary. The main conclusions are as follows:

1. With the decrease of vegetation density, the tortuosity of hydrodynamic axis increases, and the longitudinal velocity of main channel in each section decreases obviously.

2. With the decrease of the density of the rigid vegetation, the longitudinal and transverse turbulence intensity of the main channel is basically the same, the value of the transverse turbulence intensity is similar to the value of the longitudinal turbulence intensity, and the distribution law is basically the same, which may have isotropic turbulence characteristics. However, the longitudinal and transverse turbulence intensity of the slope has an obvious decreasing trend, and the value of the transverse turbulence intensity and the longitudinal turbulence intensity are different, which may have different values Turbulence characteristics of anisotropy.

3. The river roughness coefficient increases with the increase of vegetation density, which is better fitted by the quadratic polynomial line. The roughness coefficient of the river is between 0.034 to 0.045, as the vegetation density is ranged from 0 to 1000 strain/m² in this experiment.
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