Experimental Study on Flow Characteristics of Crisscross Bars in Straight Channel

Xi Wang*, Jinyou Lu[a], Zhongwu Jin[b], Zhaohui Chai[c]

Changjiang River Scientific Research Institute, Wuhan, China

[a]lujy66@vip.163.com, [b]46604357@qq.com, [c]a3515522@126.com
*Corresponding author's e-mail: wx7899@126.com

Abstract. Flow characteristics are the driving force to the riverbed evolution in straight channel with crisscross bars. The variation laws of longitudinal velocity, transverse velocity and turbulent intensity were studied by flume experiment. The results show that: ① the longitudinal time-average velocity decreases along the channel direction and its transverse distribution presents the velocity at the edge of the bar is the largest, far from the bar takes the second, and on the bar is the smallest. The transverse time-average velocity is mainly the periodic change of flow direction. ② the longitudinal turbulence intensity tends to increase along the channel, which the increase amplitude decreases from upstream to downstream. The transverse turbulence intensity is mainly the largest in the middle of the bar, followed by the head and the tail.

Keywords: Straight channel; Flume experiment; Flow velocity; turbulence intensity.

1 Introduction

Straight channel is a typical river type in natural rivers, widely existing, such as the Jiepai reach, Taipingkou reach, Tianxingzhou reach, Dongliu reach in the middle and lower reaches of the Yangtze River. Its main feature is the crisscross distribution of banks on both sides. And its evolution has always been emphasized.

Previous researches mainly focus on the formation mechanism and the characteristics of water and sediment transport of crisscross bars [1-4]. With the human activities, especially the construction and operation of large water conservancy projects, the downstream riverbed is nearly scoured by clean water, and the original balance moves to a new balance. In view of this, lots of researches were conducted by analysis, laboratory experiment and numerical simulation. For example, Xia et al. [5] analyzed the evolution characteristics of Jiepai reach in the lower reaches of the Three Gorges Reservoir and the impact on the channel condition. Lu and Yao [6] studied the impact of upstream reservoirs on the evolution of typical reaches of the Yangtze River; Liu et al. [7] studied the section shape and riverbed change of different river types downstream

P. Xiang et al. (eds.), *Proceedings of the 2023 5th International Conference on Hydraulic, Civil and Construction Engineering (HCCE 2023)*, Atlantis Highlights in Engineering 26,
https://doi.org/10.2991/978-94-6463-398-6_83

the dam after the impoundment of Xiaolangdi Reservoir on the Yellow River. Li [8] simulated the formation process of the bank under the condition of channel erosion. Shi et al. [9] studied the influence of water and sediment conditions on the evolution of crisscross shoals along straight channel.

In general, lots of researches on the evolution of the downstream straight channel of the reservoir were carried out, but there are still some deficiencies in the understanding of the horizontal and vertical changes of the flow velocity, turbulence characteristics, etc. Therefore, the flow characteristics of the crisscross bars along the straight channel were studied.

2 Materials and method

2.1 Experimental design

The experiment was carried out in a flume with the dimension of 40×2.6×1m and the bottom gradient of 1.5‰. The flume is composed of water pump, water transmission pipeline, test water tank, collecting tank, and so on. The inlet adopted an automatic water control system to govern the flow discharge with an accuracy of 0.5%. A measuring needle was used to dominate the outlet water level. Ten measuring pins were arranged every 5m on the guide wall at the right side of the water tank. Four bars were set on the both sides according to the statistical dimensions of the bars in typical reaches of the Yangtze River, which the height of is 13cm, the maximum length of the bottom is 3.81m, the maximum length of the top is 2.72m, the maximum width of the bottom is 0.7m, and the maximum width of the top is 0.35m. The distance between the two nearest bars is 4.06m, as shown in Figure 1.

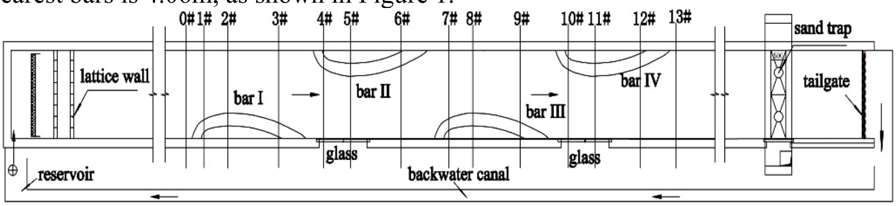


Fig. 1. Schematic diagram of flume experiment

2.2 Test and measurement contents

This experiment is to study the flow characteristics under the influence of the bar, and the flooding conditions were employed with the upstream flow discharge of 215m^3/s and the downstream water level of 18.72cm. Taking the cement surface on the left bank of section 0 # as the coordinate origin (section 0 # is located 0.2m in front of the test section), the *X*, *Y*, and *Z* axis points to the downstream, the left bank and the bottom, respectively. Fourteen sections were arranged at unequal intervals in the X-axis. The flowing characteristics were studied by Acoustic Doppler Velocimeter (ADV) measurement techniques. Sections 1 # to 12 # was distributed at the head, middle and tail of the four bars, and the section 13 # was located at the end of the flume, as shown in Figure 1. At each section, measuring points were set determined by the lateral distance and vertical height. For example, the first measuring point is at the position where the lateral distance is 0.1m from the starting and the vertical height is 5.2cm from the bottom. The interval of lateral distance was 0.2 or 0.3m. And the spacing of each measuring point upward is 0.5cm, 1cm, 3cm, 3cm, 3cm and 3cm. The sampling frequency and time of the ADV are 25Hz and 20s. A total of 500 samples were taken from each point, and the data was processed by the winADV.

2.3 Analysis parameters

Time-average velocity.

In turbulent flow, fluid particles are mixed with each other and move in disorder, and the velocity have stronger pulsation phenomenon. According to the principle of statistics, it is more significant to use statistical average to study the turbulence flow, but we need to conduct multiple groups of tests at the same time under the same conditions, and process the data obtained from each test to obtain the statistical average. Obviously, this is not easy to achieve in the actual test [10]. Therefore, time-average velocity is adopted in the data processing of this test, and the calculation formula is

$$\bar{u} = \frac{1}{N}\sum_{i=1}^{N} u_i \tag{1}$$

where $\bar{u}$ is the time-average velocity, u_i is the instantaneous velocity, N is the number of samples.

Turbulence intensity.

Turbulence intensity is a characteristic value reflecting the degree of fluctuation. It can be calculated formula from

$$\sigma = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(u_i - \bar{u})^2} \tag{2}$$

where σ is the turbulence intensity.

3 Results and discussion

3.1 Time-average velocity

Distribution along the flume direction.

The distribution characteristics of time-average velocity along the flume direction were analyzed based on the cross sections at the head, middle and tail of the bar I, II, III and IV, where the starting point distance of the measuring points is 1.2m, approximately in the middle of the flume.

Figure 2 shows the distribution of longitudinal time-average velocity of bar I and IV. The *z/h* indicates the relative water depth, *z* and *h* is the water depth at the measuring point and the total water depth, respectively. The velocity at the measuring point with relative water depth above 0.7 cannot be measured due to the limitation of ADV measurement. But it basically obeys the exponential distribution from the measured points, which is consistent with natural waters. Taking the bar as a unit, the average values of bar I, II, III and IV were calculated when the relative water depth is 0.6, and obtained 77.83cm/s, 73.85cm/s, 73.37cm/s, and 68.35cm/s. the results show the longitudinal time-average velocity tends to decrease along the flume direction. Moreover, a large decrease occurs between bar I and bar II, bar III and bar IV. For a certain bar, the variation of the longitudinal time-average velocity is characterized by a small velocity at the head section and a slightly larger velocity at the middle and tail sections, but the difference is not significant (except for the point bar III).

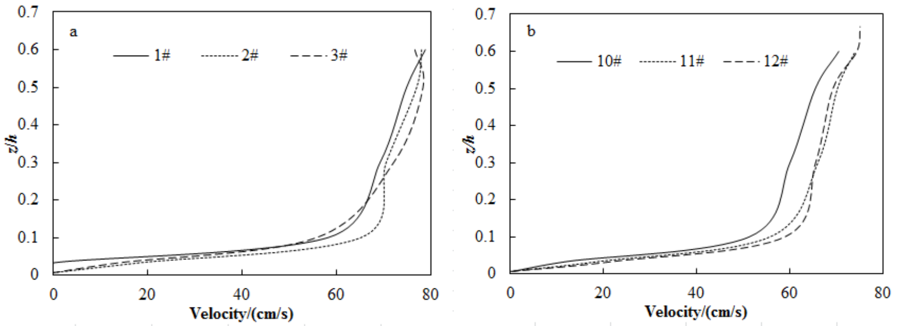


Fig. 2. Change of longitudinal time-average velocity (X direction) of different bars and sections: a. bar I; b. bar IV, where the starting point distance of measuring points is 1.2m.

Figure 3 shows the variation of the transverse time-average velocity, where a positive value indicates the transverse flow flows from the right bank to the left bank. Due to the existence of the bar, the water level on both sides is different, and a transverse flow forms. Its value and direction change with the different position. It is mainly shown as follows: when the water flows into the bar I from upstream, the transverse time-average velocities of the head and middle part are positive, and the water flows from right bank (the side of the bar) to the left bank due to the existence of the bar. However, this effect gradually decreases under the influence of centrifugal force, and the transverse velocity has become negative at the end of the bar. After continuing to enter the bar II, the transverse time-average velocity is still negative and increases as the bar II is arranged on the left side. And it gradually decreases because of the influence of centrifugal force. At the end of the second bar, the transverse flow velocity decreases to -4.01cm/s. The change of transverse time-average velocity along the third and fourth bar is similar to the former, so it is not repeated here.

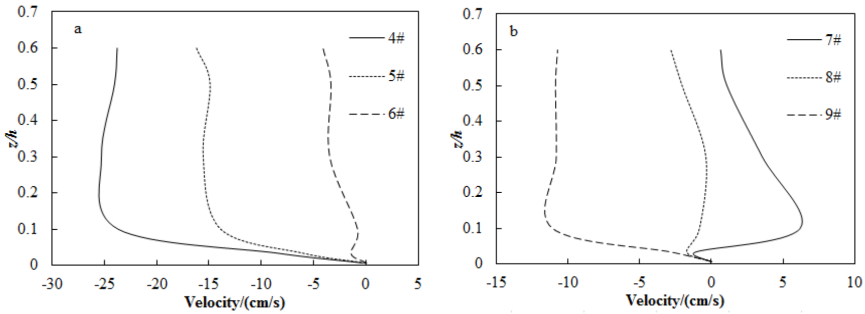
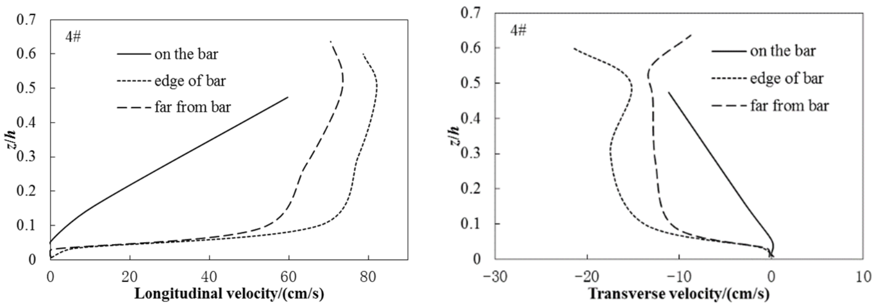


Fig. 3. Change of longitudinal time-average velocity (Y direction) of different bars and sections: a. point bar II; b. point bar III, where the starting point distance of measuring points is 1.2m.

Transverse distribution.

Sections at the head (4 #), middle (5 #) and tail (6 #) of bar II were selected to study the transverse distribution, and the section was divided into three parts: on the bar (distance from 0.3m to 0.5m), edge of bar (distance from 0.7m to 0.9m) and far from bar (distance of 1.7m). Figure 4 shows the longitudinal and transverse distribution on the head and the middle of the point bar II. As the vertical time-average velocity does not change significantly, it is not shown in the figure. It can be seen from the figure that the longitudinal time-average velocity is significantly distributed along the transverse direction. And the velocity at the edge of bar is the largest, followed by the velocity far from bar, and the velocity on the bar is the smallest. This law is more obvious in the middle and tail sections. The change of transverse time-average velocity is slightly different at the head, middle and tail sections. The head section shows that the transverse time-average velocity gradually decreases with the distance from the bar. On the other hand, the middle section is characterized by the maximum velocity at the edge, the velocity far from bar takes the second and the minimum flow velocity is on the bar. And the edge section behaves the same, which is related to the distribution of transverse time-average velocity along the flume direction.



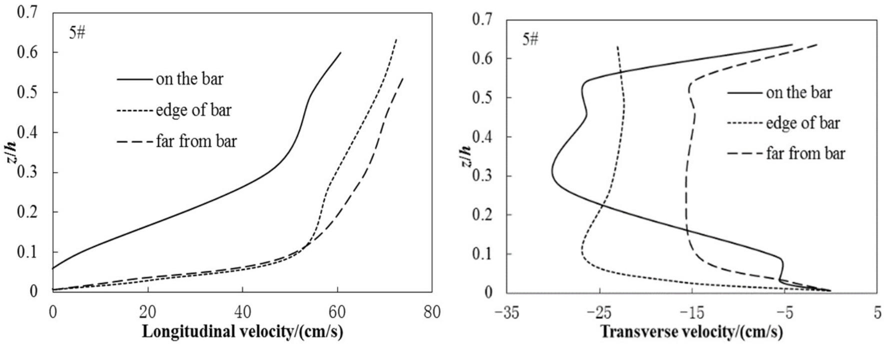


Fig. 4. Variation of longitudinal and transverse time average velocity at different positions of bar II, where section 4# is on the head, section 5# is in the middle

3.2 Turbulence intensity

The changes of turbulence intensity in three directions of the head section (1 # and 7 #), the middle section (2 # and 8 #) and the tail section (3 # and 9 #) of point bar I and III were studied, where the starting point distance of measuring points is 1.2m, as shown in Figure 5.

For the vertical distribution, it can be seen from the figure that the longitudinal turbulence intensity near bottom area is the largest, and the intensity changes little at the relative water depth between 0.3 and 0.6. The vertical distribution characteristics of transverse and vertical turbulence intensity are similar, but the turbulence intensity decreases in turn.

For the distribution along the flume direction, the longitudinal turbulence intensity tends to increase along the path, and the increase amplitude shows as decreasing from upstream to downstream. For example, the average turbulence intensity from bar I to bar III increases from 4.39cm/s to 4.94cm/s, and the longitudinal turbulence intensity raises 50.3% from the head to the tail of point bar I, while it increases by 5.63% of bar III. The variation characteristics of transverse turbulence intensity along the flume are mainly related to the shape of the bar, which is shown as the largest in the middle, followed by the head and tail, but the difference between the latter is not significant, such as, the average value of the transverse turbulence intensity at the middle of the bar I is 2.90 cm/s, and the values at the head and tail section are 2.43 cm/s and 2.32 cm/s respectively. The vertical turbulence intensity is relatively small, which is about 1/3 of the longitudinal turbulence intensity, and an increasing trend also appears. However, the shape of bar has little influence.

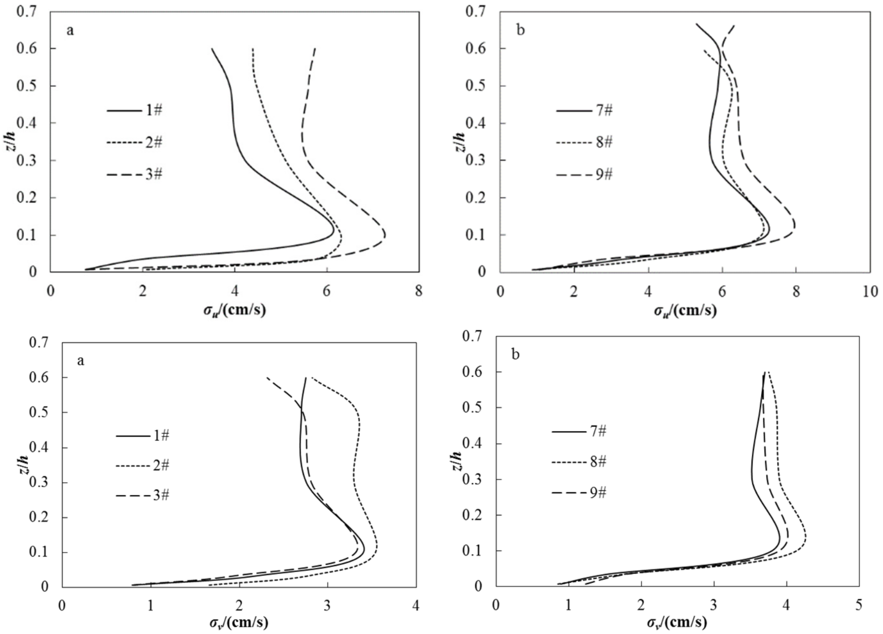
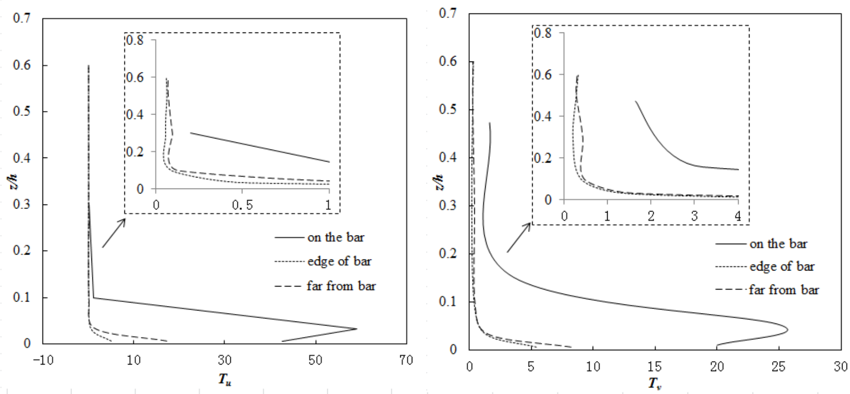


Fig. 5. Changes of turbulence intensity at typical locations of different point bar: a. point bar I; b. point bar III where the starting point distance of measuring points is 1.2m.

Taking the middle section (5 #) of bar II as an example, the transverse distribution characteristics of turbulence intensity was studied. Due to the large difference in the velocity of these three parts, the relative turbulence intensity *T* was used, as shown in Figure 6. It can be seen from the figure that the longitudinal, transverse and longitudinal relative turbulence intensities is the largest on the bar, followed by the part far from bar, and the minimum at the edge, moreover, the latter has little difference.



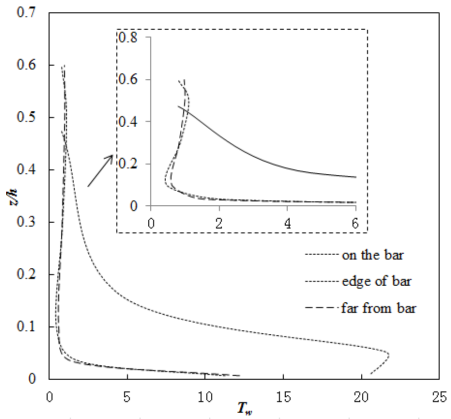


Fig. 6. Transverse distribution of relative Turbulence Intensity in three directions on the section 5 # on the point bar II

4 Conclusions

The impact of crisscross bars on the velocity and turbulence intensity in straight channel were studied through laboratory tests. The results show that the existence of bar has an important influence on velocity and turbulence intensity, and the influence changes with the position and shape of crisscross bars. As the test was carried out under single factor, which is different from natural rivers, it will be further studied in combination with on-site observation.

Acknowledgment

This work was mainly supported by National Natural Science Foundation of China [grant numbers: U2240206] and Special Fund for Basic Scientific Research Business of Central Public Research Institutes [grant numbers: CKSF2023189/HL].

References

1. Ni, J.R., Wang, S.J. (2000) On straight river Journal of Hydraulic Engineering, 12: 14-20. (in Chinese)
2. Eekhout, J.P.C., Hoitink, A.J.F., Mosselman, E (2000) Field experiment on alternate bar development in a straight sand-bed stream. Water Resources Research, 49: 8357-8369.
3. Xu, H.Y., Bai, Y.C. (2012) The nonlinear theory for sediment ripple dynamic process of straight river. Sci China Tech Sci, 42: 603-621. (in Chinese)
4. Defina, A. (2003) Numerical Experiments on Bar Growth. Water Resources Research, 39: 1085-1092.

5. Xia, J.Q., Lin, F.F., Zhou, M.R., et al. (2020) Recent morphodynamic evolution of the Jiepai reach and its effect on the navigation condition. Journal of Basic Science and Engineering, 28: 28-39. (in Chinese)
6. Lu, J.Y and Yao, S.M. (2018) Response mechanism of the river and lakes in the middle and lower reaches of the Yangtze River under the combined effect of reservoir groups[J]. Journal of Hydraulic Engineering, 49: 36-46. (in Chinese)
7. Liu, W and Wang, S.J. (2019) Temporal and spatial change of the sedimentation rate on the channel cross-sections in the lower reaches of Yellow River and its influence factors. Research of Soil and Water Conservation, 26:167-174. (in Chinese)
8. Li, M. (2018) Preliminary experimental study on the formation of bars in a straight channel under scouring condition. Hubei: Wuhan, Wuhan University. (in Chinese)
9. Shi, Q., Zhang, X.F., Xu, Q.X. (2020) Evolution of alternate bars in straight channel under different discharge and sediment conditions Journal of Yangtze River Scientific Research Institute, 37: 7-13, 24.
10. Shi, K. (2007) Study on turbulence characteristics of curved channel flow. Chongqing: Chongqing Jiaotong University. (in Chinese).