Conference Paper, Published Version

Yang, Kejun; Liu, Xingnian; Huang, Er; Cao, Shuyou

Stochastic Nature of Overbank Flow Turbulence in Straight Compound Channels with Vegetated Floodplains

STOCHASTIC NATURE OF OVERBANK FLOW TURBULENCE IN STRAIGHT COMPOUND CHANNELS WITH VEGETATED FLOODPLAINS

Kejun Yang[1], Xingnian Liu[2], Er Huang[3], Shuyou Cao[4]

[1] Lecturer, State Key Laboratory of Hydraulic and Mountain River Engineering, Sichuan University, Chengdu, Sichuan 610065, China, email : yangkejun@163.com
[2]Professor, State Key Laboratory of Hydraulic and Mountain River Engineering, Sichuan University, Chengdu, , Sichuan 610065, China
[3]Associate Professor, State Key Laboratory of Hydraulic and Mountain River Engineering, Sichuan University, Chengdu, , Sichuan 610065, China
[4] Professor, State Key Laboratory of Hydraulic and Mountain River Engineering, Sichuan University, Chengdu, , Sichuan 610065, China

ABSTRACT

Understanding the stochastic nature of overbank flow turbulence in a compound channel with vegetated floodplain is very important for determining flow resistance, sediment transport, channel process and bank protection. In this paper, the stochastic nature of turbulence of overbank flows over vegetationwere experimentally studied. The experiments were undertaken in a movable bed flume, 16 m long, 0.3 m wide and 0.4 m high, at the State Key Laboratory of Hydraulics and Mountain River Engineering of Sichuan University. For vegetation on the floodplain, the authors chose plastic straws as model trees A three-dimensional Acoustic Doppler Velocimeter (ADV) was used to measure the local flow velocities. For all cases, the fluctuation of flows shows distinct randomicity and periodicity. The fluctuating velocity follows approximately a normal distribution. The time-averaged velocity is related to the sampling duration. The turbulence intensity increases after the floodplain is vegetated. The lateral and vertical ones are proximately equal. The turbulence intensities at different locations across the channel are different. On the whole, the turbulence of flow is the most intensive at the interface between the main channel and its associated floodplains.

Key words: stochastic nature, straight compound channels, vegetated floodplains, fluctuating velocity, time-averaged velocity, momentum transfer, turbulence intensity, overbank flow

1. INTRODUCTION

In natural rivers, there are often many kinds of vegetation on the floodplains. Vegetation generally increases the flow resistance, changes the velocity distribution and affects the discharge capacity and sediment transport rate. Recently, some scholars have begun to undertake the study of the hydrodynamics of compound channes with vegetated floodplains. The experimental results of Huang et al. (2002) showed that the velocity in the main channel increased significantly after the floodplains were covered in vegetation. Darby and Thorne (1996) developed a physically based method for predicting the impact of vegetation growth on flow resistance and flood capacity. Naot et al. (1996a) examined various numerical models for analyzing unstable patterns of overbank flow in partially vegetated channels. They compared predictions given by three types of algebraic stress model. Naot et al. (1996b) further discussed the hydrodynamic response of turbulent flow in a compound wide rectangular open channel, with specific vegetated domains. Thornton et al.

(2000) examined experimentally the apparent shear stress on the interface between the main river channel and vegetated, and non-vegetated, floodplains. Kang and Choi (2004) used a Reynolds Stress Model, with a pressure-strain correlation term, to model overbank flow with vegetated floodplains, taking into account the anisotropy of the turbulence at the free surface. Järvelä (2002) analyzed the influences of different types of vegetation on Darcy-Weisbach resistance coefficent. Darby (1999) developed a model that considers the effect of riparian vegetation on flow resistance and flood potential. Fathi-Maghadam & Kouwen (2000) used individual pine and cedar tree saplings and branches used to model the resistance to flow in a water flume for nonsubmerged and nonrigid vegetation to determine the amount that streamlining decreases the drag coefficient and reduces the momentum absorbing area. Helmiö (2002) developed an unsteady flow model was for a channel with vegetated floodplains, to take into account the retention effects of the vegetated areas on flood wave conveyance. In addition, Yoshida & Dittrich (2002) also proposed a relatively simple unsteady flow model was which estimates velocities, friction factors and the components of discharge in the main channel and on the floodplains simultaneously.

For a compound channels with vegetated floodplains, how does turbulence intensity vary? What distribution do fluctuating velocities follow? Does the sampling duration affect on time-averaged velocity? How does momentum transfer on the vertical interface between main channels and floodplians? All the issues are worth investigating. Hence, some experiments were undertaken in compund channels vegetated floodplain in order to elucidate Stochastic nature of overbank flow turbulence.

2. EXPERIMENTAL ARRANGEMENTS

The experiments were undertaken in a movable bed flume, 16 m long, 0.3 m wide and 0.4 m high, at the State Key Hydraulics Laboratory of Sichuan University. The flume was operated under a uniform flow condition, and measurements of discharge, point velocity and turbulence intensity taken. Flow depths were measured by means of a pointer gauge, discharges were measured by a triangular weir, installed upstream of the channel, and the turbulence measurements were undertaken by ADV.

For vegetation on the floodplain, the authors choose plastic straws as model trees. Model vegetation was planted on the floodplain over a length of 3 m, between 8.2 m and 11.2 m from the beginning of the compound channel. Model vegetation was planted in an interlaced way, i.e. the vegetation in the second row was on the centerline of the adjoining vegetation in the first row. For each type of vegetation, the row spacing was the same, i.e. 3 cm, but their plant spacings were different, i.e. 3 cm, 4 cm, and 2 cm, respectively.

Within the measurement cross-section, located at 9.6 m, the authors arranged ten verticals, as shown in Figure1, where the lateral values of y (cm) from the first vertical to the last were 4, 6, 8, 11, 14, 17, 19.5, 22, 24.5 and 26.5, respectively. When the vertical distance from the measurement point to the bed was less than 5 mm, the measurement interval was reduced to 1 mm, and when the distance was larger than 5 mm, the measurement intervals were 2.5 mm, 4 mm & 5 mm, according to the particular flow depth. Bed slope, S_0, is considered as. $1.25^0/_{00}$. Each type of vegetation was tested for at least three discharges, 10.95, 14.11 and 17.72 l/s. In certain cases a discharge of 22.21 l/s was also used

An asymmetric compound channel was moulded, using a non-uniform sediment with median diameter of 0.4 mm, into the shape of the cross-section shown in Figure 1. The main channel and floodplain had widths of 8 cm and 13 cm respectively, and the main channel had a side slope, s, of 1.5. The bankfull height, h, was 6 cm.

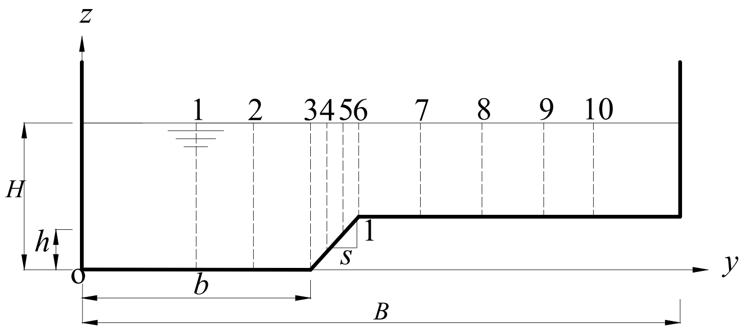

Figure 1 Cross section of an asymmetric compound channel

3. VELOCITY DISTRIBUTION

Fluctuating velocities

The raw data were sampled at 50 Hz over a period of 30 seconds at each measurement position within the cross-section. The sampling periods were thus sufficiently long to ensure that an adequate number of turbulent bursts were recorded. From a statistical analysis of the raw data, it was found that the distributions of the fluctuating velocities along three directions follow approximately normal distributions, as shown in Figure 2. However, when the fluctuating velocity approaches zero, the measured data depart somewhat from the full line. The full line in Figure 2 is plotted according to the following equation.

$$f(u_i) = \frac{1}{\sigma_i \sqrt{2\pi}} e^{-\frac{u_i^2}{2\sigma_i^2}} \tag{1}$$

where f = probability density, u_i = fluctuating velocity in the i direction, i.e. u, v and w, σ_i = standard deviation of u_i. Thus σ_i actually reflects the intensity of the turbulence in the i direction. The value of y for the point of intersection of the full line and the y axis can also reflect the intensity of the turbulence. After the floodplain is vegetated, turbulence intensities of flow increase. The lateral and vertical ones are proximately equal.

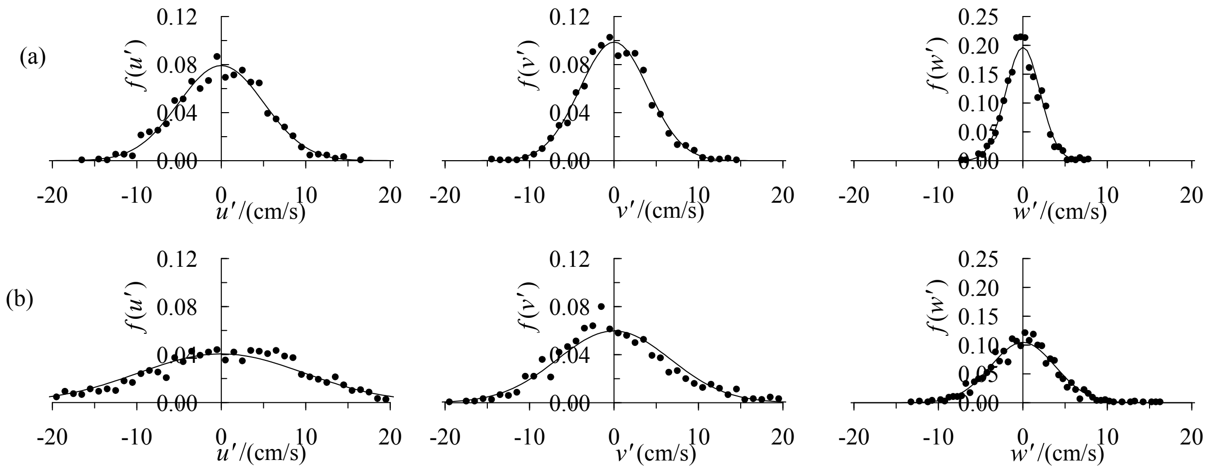

Figure 2 The distribution of fluctuating velocities for different vegetation, at y = 17 cm and z_p = 1 cm, with $S_0 = 1.25^0/_{00}$ and Q = 17.72 l/s.

(a) for no vegetation (b) for vegetation

Time-aveaged velocity

Time-averaged velocity U is computed using the following equation,

$$U = \frac{1}{t}\int_{T_0}^{T_0+t}\widetilde{U}(T)dT \qquad (2)$$

where $\widetilde{U}(T)$ is the instantaneous velocity at T, T_0 is the initial time, t is the sampling duration. From Eq. (2), the time-averaged velocity is related to the sampling duration. For a given measrured point, how long is the sampling duration so that the obtained time-averaged velocity should be effective? Hence, the paper undertakes the following analysis,

If there is a groud data as follows,

$\widetilde{U}_0$, $\widetilde{U}_1$, $\widetilde{U}_2$, $\widetilde{U}_3$, $\widetilde{U}_4$, $\widetilde{U}_5$, ……, $\widetilde{U}_{n-4}$, $\widetilde{U}_{n-3}$, $\widetilde{U}_{n-2}$, $\widetilde{U}_{n-1}$, $\widetilde{U}_n$

the corresponding time is

T_0, T_1, T_2, T_3, T_4, T_5, ……, T_{n-4}, T_{n-3}, T_{n-2}, T_{n-1}, $T_{n.}$

Hence, the time-aveaged value frome T_0 to T_i (i=1, 2,……, n) may be determined. For different T_i, there is a corresponding value of sampling duration, t (t=T_i-T_0). As a result, the relationshipbetween the time-aveaged value and sampling duration is obtained. For the corresponding instantaneous velocities in Figure 2, the relationship between the time-aveaged velocity and sampling duration is shown in Figure 3, where U, V and W are the time-averaged velocities in the x-, y- and z- directions. From Figure 3, when the sampling duration is less than certain value, time-aveaged velocity varies largely. On when the sampling duration is large than certain value, does time-averaged velocity approach cerntain constant.

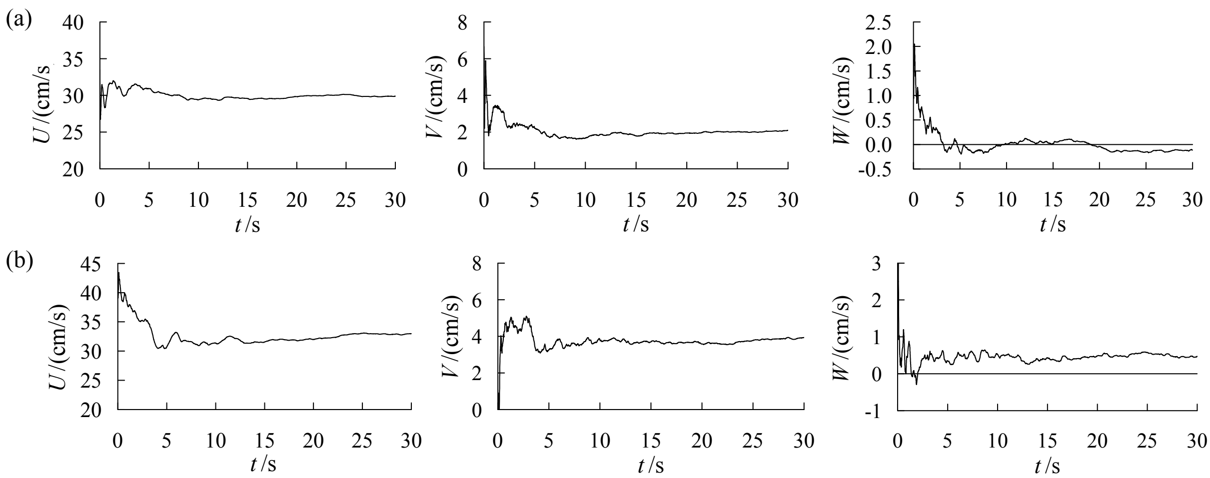

Figure 3 Effect of sampling duration on time-averaged velocity (y=17cm, z_p=1cm, Q=17.72 l/s, S_0=1.25‰)
(a) for no vegetation (b) for vegetation

4. TURBULENCE INTENSITIES

The turbulence intensity, σ_i, in i direction, was calculated from the velocity data according to

$$\sigma_i = \sqrt{\overline{u_i^2}} \qquad (7)$$

However, many researchers prefer the relative turbulence intensity, σ_{ir}, given by

$$\sigma_{ir} = \frac{\sqrt{\overline{u_i^2}}}{V_A} \tag{8}$$

where V_A is the mean cross-sectional velocity.

The variations in the streamwise, lateral and vertical turbulence intensities over the depth are shown in Figure 4 for two locations, y = 8 cm and y = 17 cm, i.e. at the inner edge of the base of the main channel and at the upper edge of the main channel/beginning of the floodplain respectively.

From Figure 4, after the floodplain is vegetated, the turbulence intensity increases. By comparing the distributions in 3 directions, it is found that the streamwise and lateral intensities are approximately equal. In the figures, $Hr = z_p / H(y)$ is called the relative depth, where H(y) = flow depth at the location y.

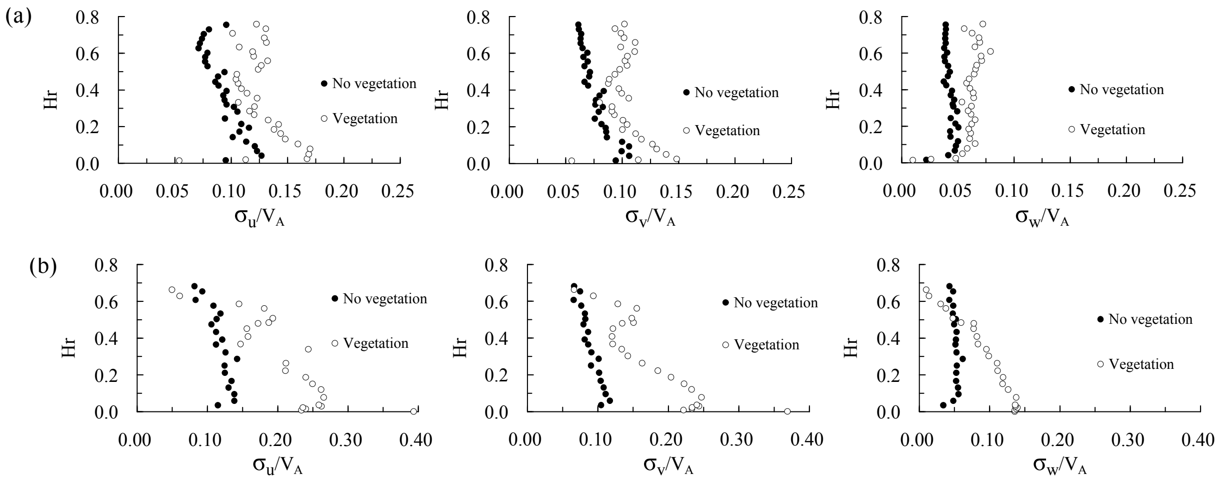

Figure 4 Vertical variation of turbulence intensity for streamwise, lateral and vertical directions at different locations, with Q = 17.72 and S_0 = $1.25^0/_{00}$.
(a) at y = 8 cm (b) at y = 17 cm

5. CONCLUSIONS

(1) The turbulence of flow shows the strongly periodic and stochastic nature. The vegetation on the floodplains affects the fluctuation of flow. After the floodplain is vegetated, flow fluctuation increases. The turbulence intensities at different locations across the channel are different.

(2) The fluctuating velocities in the streamwise, lateral and vertical directions follows approximately normal distributions. When the fluctuating velocity approaches zero, the measured data depart somewhat from the normal distributions.

(3) The existence of vegetation will increase the turbulence intensity of flow. The streamwise and lateral intensities are approximately equal.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support of the National Natural Scientific Foundation of China (No. 50579041, 50679048)..

REFERENCES

Darby, S.E., Thorne, C.R.(1996), Predicting stage-discharge curves in channels with bank vegetation, *Journal of Hydraulic Engineering*, ASCE, 122(10), pp.583-586.

Darby, S. E. (1999), Effect of riparian vegetation on flow resistance and flood potential., *Journal of Hydraulic Engineering*, ASCE, 25(5), pp.443-454.

Fathi-Maghadam, M., Kouwen, K. (2000), Nonrigid nonsubmerged vegetative roughness on floodplains, *Journal of Hydraulic Enginering*, ASCE, 126 (1), pp.51-57.

Helmiö, T. (2002), Unsteady 1D flow model of compound channel with vegetated floodplains, *Journal of Hydrology*, 269, pp. 89-99

Huang, B., Lai, G., Qin., J., et al. (2002), Hydraulics of compound channel with vegetated floodplains, *Journal of hydrodynamics*, Ser. B, 14(1), pp.23-28.

Järvelä, J. (2002). Flow resistance of flexible and stiff vegetation: a flume study with natural plants, *Journal of Hydrology,* 269, pp. 44-54.

Kang, H., Choi, S.U. (2004), 3D numerical simulation of compound open channel flows with vegetated floodplains by Reynolds stress model. In: Sehlke G, Hayes D F, Stevens D K eds. The 2004 World Water and Environmental Resources Congress. Salt Lake City: American Society of Civil Engineers Press, 2004.

Naot, D., Nezu, I., Nakagawa, H. (1996a). Unstable patterns in partly vegetated channels, *Journal of Hydraulic Engineering,* ASCE, 122(11), pp.671-673.

Naot, D., Nezu, I., Nakagawa, H.(1996b) Hydrodynamic behavior of partly vegetated open channels, *Journal of Hydraulic Engineering*, ASCE, 122(11), pp.625-633.

Thornton, C.I., Abt, S.R., Morris, C.E., et al.(2000), Calculating shear stress at channel-overbank interfaces in straight channels with vegetated floodplains, *Journal of Hydraulic Engineering*, ASCE, 2000, 126(12): 929-936.

Yoshida, H., Dittrich, A. (2002), 1D unsteady-state flow simulation of a section of the upper Rhine, *Journal of Hydrology*, 269, pp.79-88.