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PRELIMINARY STUDY OF LARGE WOOD MOTION NEAR A CHANNEL CONFLUENCE

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Abstract

Knowledge of motions of large wood near river confluences is important for prediction of wood distribution in a river network, and wood distribution is a key factor affecting flow, sediment transport and riverbed evolution. The separation zone near the confluence of a river network is a usual gathering place for large wood. In this study, a series of laboratory experiments were done to determine the motion responses of large wood to the hydrodynamic forces near the separation zone of channel confluence. A single wood was released at the tributary upstream and its motion and trajectory near the separation zone was recorded by infrared thermal imaging. Different sizes of woods (with different diameters and lengths) and discharge ratios of flow confluence (ratio of the tributary discharge to the total flow discharge) were considered. Each case was repeated for 30 times. The results showed there were two main motion patterns of wood which entered the separation zone: (1) the wood touched the sharp corner wall, and rotated at a certain angle due to the friction of the wall and entered directly into the upstream part of the separation zone; (2) the wood did not touch the sharp corner wall, and travelled along the boundary of the separation zone; and then it rotated due to the strong flow shear and entered into the downstream part of the separation zone. In addition, the number of woods entering the separation zone increased when the confluence ratio increased. The wood with larger length had a higher probability of entering the separation zone. These observations provide important knowledge on motion of large wood near river confluences and are beneficial for disaster prevention and control related to the wood blocking in the river network.
Keywords: Large Wood; Channel Confluence; Separation Zone; Laboratory Experiment

1. INTRODUCTION

River confluences are common in natural water systems. They are critical nodes in a river network and play important roles in the transport of water, sediment and pollution. Large wood (LW, defined as wood in rivers arising from downed trees with a body larger than 1 m in length and 10 cm in diameter; Wohl et al., 2010) are sometimes observed to stagnate within the separation zone of river confluences. LW plays a critical role in sediment transport, promoting flow resistance, providing habitat for riparian aquatic organisms (Wohl & Scott, 2017; Comiti et al., 2008; Curran & Wohl, 2003; Scott et al., 2014; Wohl, 2016). Previous studies mainly focused on behavior of LW in a straight open channel such as mobilization, transport, jam and depositional processes of LW. For instance, the irregularities of LW affected its stability, and the presence or absence of rootwads in LW largely affected their transport distance as suggested by S.L. Davidson et al. (2015). Some laboratory studies have been attempted to figure out the complex wood-flow interaction in open channels, e.g., Schalko et al. (2020) and Okamoto et al. (2020). LW tends to deposit or block the channel when it encounters some obstruction; for instance, LW can accumulate at bridge piers and the accumulation probability is mainly determined by approach flow velocity and log length (Isabella Schalko et al., 2019). The blocking of LW is also easy to occur when the channel is shallow or narrow (Braudrick et al., 1997). Braudrick and Grant (2001) suggested that the travel distance of a piece of wood (the distance from its release to where it stops) decreased as the ratio of wood length to both channel width and radius of curvature increases. However, the flow structure near a channel confluence is much more complex with the co-existence of shear layers, flow separation and flow stagnation (Yuan et al., 2018; Yuan et al., 2021), which make the behavior of LW near the confluence unpredictable. The present study conducted a series of laboratory experiments to attempt to decide the motion responses of large wood to the hydrodynamic forces near the channel confluence. It can provide preliminary knowledge on motion of large wood near river confluences and be beneficial for disaster prevention and control related to the wood blocking in the river network.

2. EXPERIMENT SETUP

A series of experiments were conducted to investigate the behavior of model LW in a flume confluence in the State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering of Hohai University. The flume is schematically shown in Fig. 1. The total length of the flume is 10 m. Both the main channel and the tributary are 3 m long and 0.32 m wide, and the length of the post-confluence channel is 7 m, and the width is 0.42 m. The ratio of the width of the post channel to that of the upstream branches, about 1.3, corresponds to that of river confluences. The water is pumped from the downstream tank to the two upstream tanks via 110 mm diameter PVC pipes, and the flow discharge is strictly controlled by two ultrasonic flow meters and a pump valve system. Beehives and sufficiently long channels are used to ensure that the flow into the junction is fully developed. The water stage is regulated by a tailgate downstream. All channels have a rectangular cross section and a flat bottom.

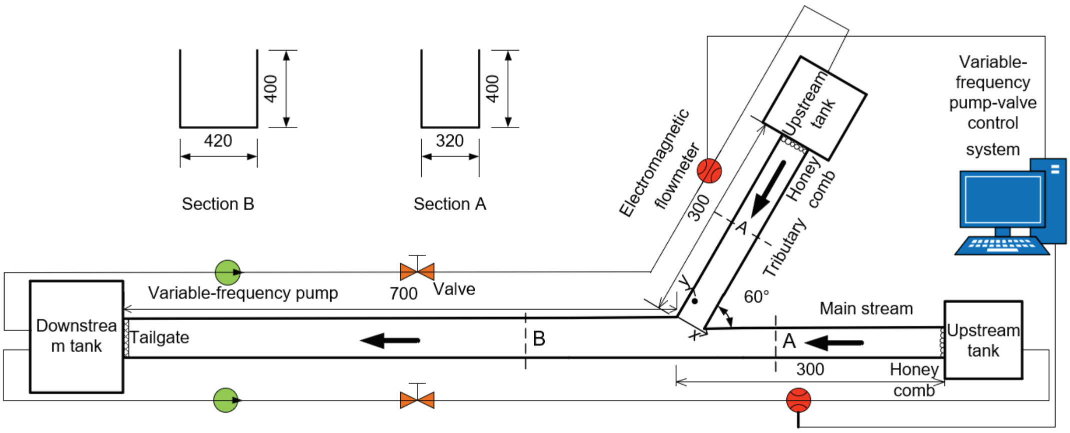

Figure 1. Confluence flume plane layout. The black dot represents the location where a single LW are released. (Unit: mm).

The model LW were composed of Betula platyphylla logs with a density of 650 kg/m^3 as real trees which was less than water. They were processed into a cylinder with a smooth surface. They have different lengths (5, 10, 12 and 15 cm) and different diameters (0.5, 1.5 and 2.0 cm). To record the motion of LW near the confluence, an infrared camera was placed 2 m over the flume to take pictures with 25 Hz framerate.

At the beginning of the experiment, a single LW was released to the approach flow from the tributary or the upstream of the main channel. The angle of supplied LW was parallel to the flow direction as the LW drifted in the water for a certain distance. The position of the LW released from the tributary was at (2 cm, 40 cm) as marked with a black dot in Fig. 1. In the mainstream, the LW was released randomly within the cross-section. Each case was repeated 30 times to decrease the error as suggested by Furlan et al. (2020). Then, the following experiments were conducted:

(1) We evaluated the probability of the LW entering the separation zone with the fixed hydraulic condition. The water stage, *h*, was 20 cm. The flow rates of main channel and tributary are 6 L/s and 14 L/s, respectively, and thus the confluence ratio, *q*, was 0.7 where $q = Q_T/(Q_T+Q_M)$. Whether the single LW was trapped in the separation zone or not, it was removed before the next test.

(2) We also investigated the probability of a certain LW with 15 cm in length and 2 cm in diameter entering the separation zone under the different hydraulic condition and with the different place for wood release. That is, the LW was released from the tributary or from the main channel; and the confluence ratios *q* varied in steps of 0.1 between 0.3 and 0.7 with a fixed total flow rate 20 L/s and a fixed water stage 20 cm. These cases with different discharge ratios are shown in Table 1.

Besides the probability calculation, we also studied the patterns of LW entering the separation zone from the tributary with continuous pictures.

Table 1. Hydraulic parameters at different discharge ratios

Confluence ratio q (-)	Q_T (L·s^{-1})	Q_M (L·s^{-1})	Re (-)		Fr (-)	
			Tributary flow	Main flow	Tributary flow	Main flow
0.3	6	14	8250	19252	0.07	0.16
0.4	8	12	11001	16502	0.09	0.13
0.5	10	10	13751	13751	0.11	0.11
0.6	12	8	16502	11001	0.13	0.09
0.7	14	6	19252	8251	0.16	0.07

Note: Confluence ratio q is the ratio of the tributary discharge to the total flow discharge; Q_T and Q_M refer to the discharges of the tributary flow and the upstream main flow, respectively; Re is the Reynolds number; Fr is the Froude number.

3. RESULTS

3.1 Entering probability when LW was released from main channel

In this series of experiments, the LW with the same size (L = 15 cm, D = 2 cm) was released randomly from the upstream of the mainstream, to study the probability of LW entering the separation zone. The confluence ratio varied in the range of (0.3, 0.7). However, no LW was observed to enter the separation zone in all runs. It seems that the LW in the upstream of the main channel has a high difficulty in crossing the shear layer between two confluent flows and entering the separation zone no matter where it was released.

3.2 Entering probability versus confluence ratio

In this series of experiments, the LW with the same size as that in Section 3.1 was released from the tributary, and the confluence ratio was varied to investigate its effect on the probability of LW entering the separation zone. In Fig. 2, a histogram is used to show the number of entries into the separation zone at different confluence ratios based on the experimental data. It seems that the wood could not enter the separation zone when the confluence ratio was smaller than 0.3. The probability of the LW entering the separation zone increased with the confluence ratio. When the confluence ratio was larger than 0.6, it seems that the entering probability got stable or even got a little decreased. The internal mechanism needs the further in-depth study.

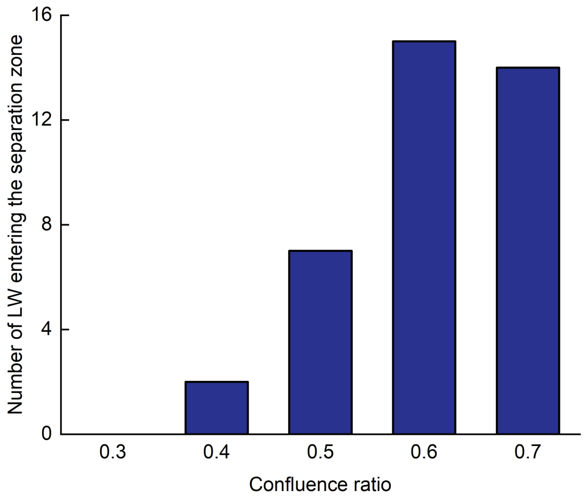

Figure 2. A histogram of the number of entries into the separation zone versus the confluence ratio.

3.3 Entering probability versus LW size

In this series of experiments, the LW with different sizes were released from the tributary to investigate the effect of LW size on the access of LW to the separation zone when the confluence ratio was fixed as 0.7 L·s^{-1}. The entering probability versus the relative LW size is showed in Fig.3 and a box plot was made statistically in Fig.4. Fig.4 shows that LW with the larger length had a higher probability of entering the separation zone. When the LW length increased from 5 cm to 10 cm, the entering probability almost doubled. As the length continued to increase, the entering number tended to stabilize. In comparison to the length, the increase in diameter of LW did not result in an evident change in the entering probability. It can be concluded that the LW length dominates for the entering probability. The effect of LW diameter needs more refined subsequent experimental studies.

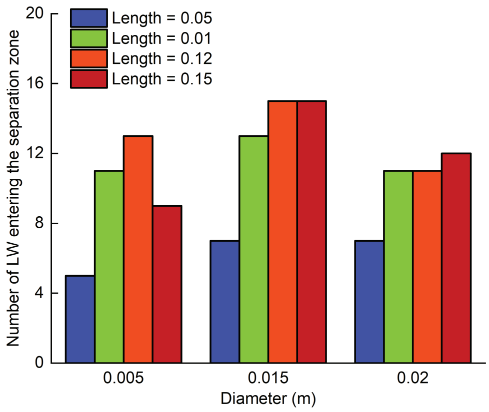

Figure 3. A histogram of the entering probability versus the relative LW size.

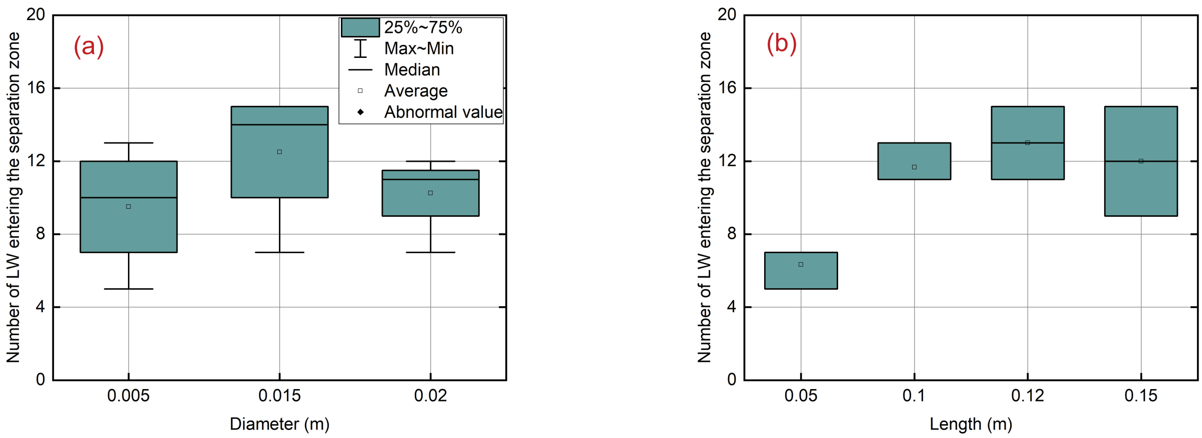

Figure 4. A box plot of the diameter (a) and the length (b) of the LW vs. the number of LW entering the separation zone.

3.4 Motion patterns of LW entering the separation zone

By continuously taking the pictures that the wood travelled at the confluence, we can preliminarily draw a conclusion that there were two main patterns that the tributary wood entered the separation zone: one is that the wood touched the sharp corner wall, and rotated at a certain angle due to the friction of the wall and entered directly into the upstream part of the separation zone; the other is the wood did not touch the sharp corner wall, and travelled along the boundary of the separation zone; and then it rotated due to the strong flow shear and entered into the downstream part of the separation zone. The patterns have different dynamic process: the former one rotated with the help of the corner wall and upstream flow, and the latter one relied on the vortex produced by the high flow velocity disparities, and thus entered the low velocity area. Fig. 5 shows these two main patterns of the LW entering the separation zone.

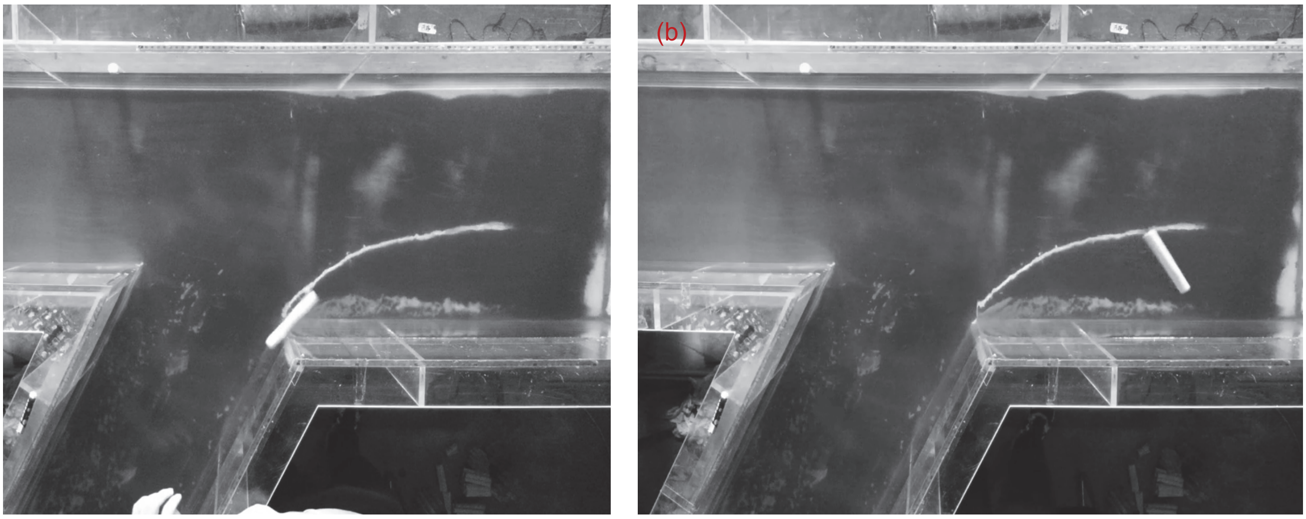

Figure 5. Two patterns for the LW entering the separation zone: (a) LW touched the sharp corner wall and rotated; (b) LW travelled along the boundary and then rotated. The white line is the boundary of the separation zone.

4. CONCLUSIONS AND OUTLOOKS

This study conducted a series of flume experiments to investigate the behavior of large wood in a channel confluence. Some preliminary conclusions can be made. The LW which was released from the upstream main channel could not enter the separation zone regardless of the confluence ratio, and it seems that the LW could not pass the shear layers between two confluent flows. For a certain size (L = 15 cm, D = 2 cm), LW appears to be difficult to access when the confluence ratio was small (less than 0.3), and the probability of the LW entering the separation zone increased with the confluence ratio because the width of the separation zone increased . For a fixed confluence ratio, LW with a longer length was easier to be trapped in the separation zone, which might be due to the larger moment of rotation. Two patterns for the LW entering the separation zone were observed: (a) LW touched the sharp corner wall and rotated; (b) LW travelled along the boundary of the zone and then rotated. However, the internal mechanism needs further investigation. These results will help to understand the LW motions near the confluence, more field survey and laboratory experiments are needed in the future for in-depth understanding of the dynamics of LW motions near the confluence.

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