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Log Jam Formation and Flood Damage to House by Detour Flood Flow around a Bridge

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ABSTRACT

At the time of localized torrential rains, large driftwood blocks the river, which lead to a decreased discharge capacity and increased water levels. However, there is almost no detailed information about the log jam formation and the flood damage to a house by a detour flood-flow around a bridge. In this study, three kinds of flume experiments were performed. For Experiment 1, we measured the pitching moment stability of driftwood to investigate the projected area (angle of attack) of driftwood. Cylinder wood pieces were used to model driftwood. We changed the gravity center position. For Experiment 2, we investigated the blocking probability of driftwood model at the model bridge. The results revealed that a blocking probability of driftwood at the model bridge is determined by the projected area of driftwood. After large amount of driftwood models accumulated around the model bridge, the backwater surface rose and the flood-flow reaches the model house on floodplain. For Experiment 3, the drag force exerted on the model house on floodplain was measured using a push-pull gage. The measured data was compared with the Wooden house demolitions criteria.

KEY WORDS: Driftwood; bridge; pitching moment; log jam; detour flood-flow; drag force; flood damage to house

INTRODUCTION

Driftwood in rivers seriously increases the destructive power of flood flow. Large driftwoods accumulate at a bridge and block the river (Fig.1), which lead to a decreased discharge capacity and increased water levels. In Uji city in August 2012, the detour flood-flow occurred around the bridge and the house along Shizugawa River was washed away. Some previous research conducted the flume study and investigated a log jam formation.

Schmocker & Hager (2011) conducted flume experiments and evaluated the drift-blocking probability at bridge decks depending on (1) driftwood dimensions (single logs and single root stocks) and (2) bridge characteristics. Prister et al. (2013) investigated the interaction between various piano key geometries and woody debris sizes. They found that the floating debris blocking probability is highly influenced by trunk diameter and upstream head. Recently, Rusyda et al. (2014) examined the relationship between a logjam and an obstruction in a channel, and proposed an empirical equation for predicting the volume of a logjam at a bridge.

Fig. 1 Log jam formation around the bridge (Sep. 2014, Fukuchiyama city)

However, still more works are needed because there is almost no detailed information about the log jam formation around a bridge and flood damage to a house by a detour flood flow in a blocked river. So, in the present study, three kinds of flume experiments (1. Pitching moment measurement of driftwood, 2. Driftwood accumulation experiment, 3. Drag force exerted on the model house measurement) were performed. The results revealed that a blocking probability of driftwood at the bridge is determined by the projected area of driftwood. After large amount of driftwood models accumulated around the model bridge, the backwater surface rose and the flood-flow reaches the house on floodplain. The measured data of drag force was compared with the Wooden house demolitions criteria.

EXPERIMENTAL METHOD

Pitching Moment Measurement

Fig. 2 shows the Pitching moment experimental set-up. The experiments were conducted in a 10m long and 40cm wide glass-made flume. x, y and z are the streamwise, vertical and spanwise coordinates, respectively. H is the water depth.

We measured the pitching moment of driftwood by using a digital push-pull gauge. Cylinder wood pieces (d=2.0, 3.0, 5.0cm diameter and l=40cm length) were used to model driftwood. The driftwood model was half-submerged. The angle of attack α was changed at intervals of 1.0° from -15° to 15°. The 3.0mm diameter and 40cm length metal cylinder was attached to the driftwood. The attachment point corresponds to the virtual gravity center. The virtual gravity center

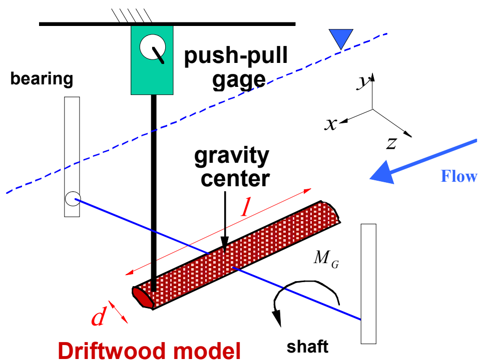

Fig. 2 Experimental setup(Pitching moment measurement)

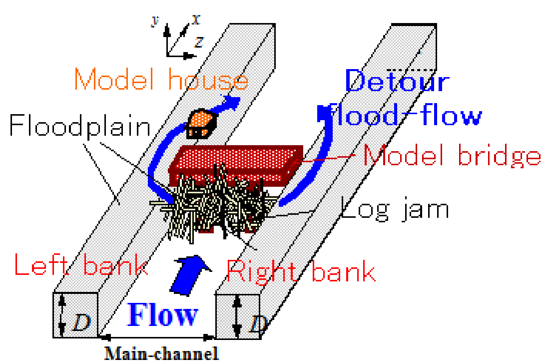

Fig. 3 Experimental setup (Driftwood accumulation experiment)

position was changed for three patterns (upstream edge, center, downstream edge). Downstream edge (Upstream edge for Case Gd-2) of the driftwood model was attached to the push-pull gauge.

We can calculate the pitching moment of the driftwood around the gravity center by using the measured value of a push-pull gauge and the distance between the (push-pull gauge) attachment point and the gravity center.

Driftwood Accumulation and Drag Force Measurement

Fig. 3 shows the driftwood accumulation experimental set-up. Floodplain models (made of hard vinyl chloride) were placed on both sides of the channel, as shown in Figs.2(b) and (c). The width of both floodplains (B_f=10cm) is half the width of Main-channel region (B_m=20cm). The bank height is constant for both bank (D =10cm).

The model bridge was mounted 4.0m from the upstream edge of the floodplain and 9.0cm above the channel bottom. The model bridge was composed of deck and two piers (1.0cm width). The bridge roadway is 20cm long, 2.0cm wide and 1.0cm thickness. The model bridge was fixed to the floodplains.

Cylinder wood pieces (6.0mm diameter and 12.0cm length) were used to model driftwood. The wood density is 0.5g/cm^3. The wood pieces were soaked in water for 1 hour prior to a test. Driftwood models were supplied to the flow at 4.0m upstream from the model bridge ($x = -4.0$ m). The number of wood pieces was 140 pieces/180s. We used a weight to change the gravity center position of driftwood model (center or upstream edge of driftwood model).

Table 1 Hydraulic condition

	Q (l/s)	U_m (m/s)	H (cm)	l (cm)	d (cm)	l/d	Fr	Gravity center
CaseGu-5	30.0	50.0	15.0	20.0	5.0	4.0	0.41	upstream edge
CaseGc-5	30.0	50.0	15.0	20.0	5.0	4.0	0.41	center
CaseGu-3	30.0	50.0	15.0	20.0	3.0	6.7	0.41	upstream edge
CaseGc-3	30.0	50.0	15.0	20.0	3.0	6.7	0.41	center
CaseGu-2	30.0	50.0	15.0	20.0	2.0	10.0	0.41	upstream edge
CaseGc-2	30.0	50.0	15.0	20.0	2.0	10.0	0.41	center
CaseGd-2	30.0	50.0	15.0	20.0	2.0	10.0	0.41	downstream edge

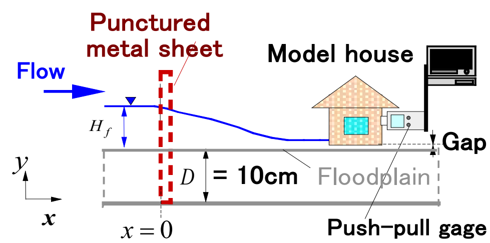

Fig. 4 Experimental setup (Drag force measurement)

After large amount of driftwood models accumulated around the model bridge, the backwater surface rises and the flood-flow reaches the house on floodplain.

Fig. 4 shows the drag force measurement set-up. Hydrodynamic force on the model house in x-direction was measured by the digital push-pull gauge with 180s sampling time. For measuring the drag force, a gap (1-2mm) is required between the model house and the channel bed to remove the effect of the bed-friction resistance (see Takemura & Tanaka (2007)). The model house was constructed of foam polystyrene, with 6cm height, 6cm width and 6cm length (1/80 scale).

Table1 shows the hydraulic condition. For Experiment 1(Pitching moment experiment), driftwood diameter was changed (d=2.0, 3.0, 5.0cm, l=40cm length). The bulk mean velocity is U_m=50.0(cm/s) and the flow depth is H=15.0cm.

For Experiment 2 (Driftwood accumulation and drag force experiment), cylinder wood pieces (6.0mm diameter and 12.0cm length) were used to model driftwood. The bulk mean velocity is U_m=30.0(cm/s) and the flow depth in Main-channel is H=8.5cm (<D=10cm).

For Experiment 3 (Drag force experiment), the bulk mean velocity is U_m=30.0(cm/s) and the flow depth in Main-channel is H =8.5cm. A punctured metal sheet (15cm height, 20cm width, 3.0mm thickness and 3.0mm hole-diameter) was placed in front of the woody model bridge in Main-channel to mimic a blocked river (due to a logjam) at a bridge.

RESULTS

Pitching Moment Stability of Driftwood

To examine the projected area of driftwood in flood flow, we investigated the pitching moment stability of the driftwood. Fig. 5 shows the pitching moment of driftwood (d=2cm) versus the angle of attack α . It is observed that the pitching stability is greatly affected by the gravity center position of driftwood. When the gravity center position was the center of the driftwood (Case Gc-2), M_{Gc} decreases with an increase of an angle of attack α (Static stability). M_{Gc} takes the positive value at $\alpha < 0°$ and M_{Gc} takes the negative value at $\alpha > 0°$. This indicates that the driftwood (Case Gc-2) is floating at $\alpha = 0°$.

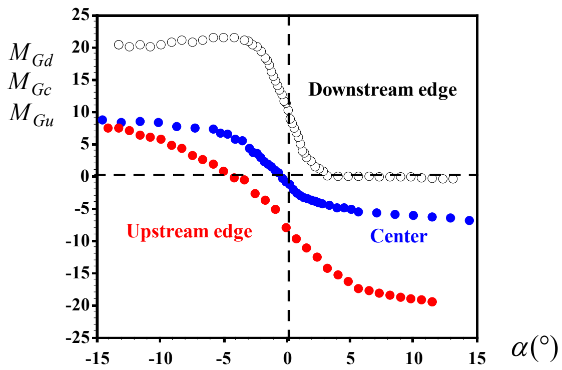

Fig. 5 Pitching moment of driftwood (*d*=2cm)

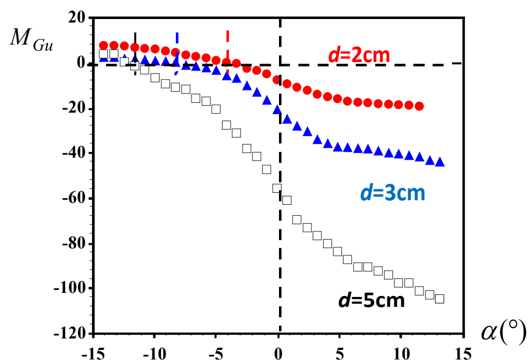

Fig. 6 Pitching moment of driftwood (gravity center: upstream edge)

When the gravity center position was the upstream edge of the driftwood (Case Gu-2), the pitching moment M_{Gu} decreases with an increase of an angle of attack α. This condition is determined as 'Static stability'. The pitching moment M_{Gu} takes the negative value at $\alpha = 0°$. The pitching moment M_{Gu} is zero at $\alpha = -4.1°$ and M_{Gu} takes the positive value at $\alpha < -4.1°$. This indicates that the driftwood (Case Gu-2) is floating at $\alpha = -4.1°$ (negative angle of attack). The projected area of driftwood becomes larger for Case Gu-2 than that for Case Gc-2.

When the gravity center position was the downstream edge of the driftwood (Case Gd-2), the pitching moment M_{Gd} decreases with an increase of an angle of attack at $\alpha < 4.1°$. M_{Gd} takes the constant value (around zero) at $\alpha > 4.1°$. This condition is determined as 'unstable condition'.

Fig. 6 shows the pitching moment of driftwood (*d*=2, 3, 5cm) versus the angle of attack α. For all cases, the pitching moment M_{Gu} decreases with an increase of an angle of attack α (Static stability). M_{Gu} takes the zero value at $\alpha = -4.1°$ (*d*=2cm, Case Gu-2), at $\alpha = -8.2°$ (*d*=3cm, Case Gu-3) and $\alpha = -12.3°$ (*d*=5cm, Case Gu-5). This indicates that the driftwood is floating at $\alpha = -4.1°$ (*d*=2cm, Case Gu-2), at $\alpha = -8.2°$ (*d*=3cm, Case Gu-3) and $\alpha = -12.3°$ (*d*=5cm, Case Gu-5).

The results revealed that as the driftwood diameter increases, the angle of attack of driftwood in flood flow becomes larger.

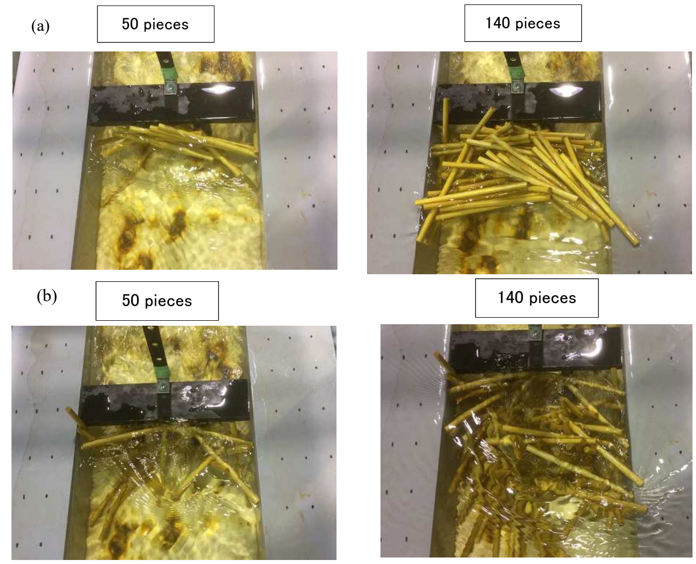

Fig. 7 Driftwood accumulation around the bridge (a) gravity center: center, (b) gravity center: upstream edge

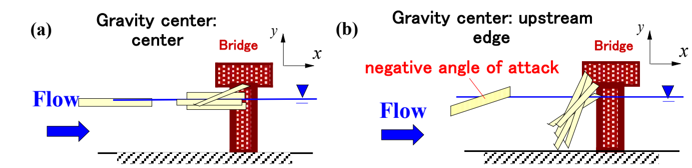

Fig. 8 Sketch of driftwood accumulation (a) gravity center:center, (b) gravity center:upstream edge

Driftwood Accumulation at Bridge

To examine the effect of the driftwood projected area on the blocking probability at a bridge, we conducted the driftwood accumulation experiment. Fig. 7 shows photographic example of the driftwood accumulation for Case1 (the gravity center location is center position) and Case2 (the gravity center location is upstream edge). For Case1, the driftwood models were floating at $\alpha = 0°$. Some wood pieces were trapped and accumulated at the bridge. The other pieces passed through the bridge. The blocking probability of driftwood is *P*=0.3-0.4.

Once a single driftwood model is trapped by the bridge, the blocking probability increases. The driftwood accumulation resulted in an increase in water level upstream from the model bridge. The flood-flow depth was H_f=0.5cm (right bank and left bank).

For Case2 (the gravity center location is upstream edge), the driftwood models were floating at $\alpha < 0°$ (negative angle of attack). The blocking probability of driftwood becomes larger (*P*=0.5-0.6) for Case2 than that for Case1. This indicates that the blocking probability of driftwood at the bridge is determined by the projected area of driftwood. After large amount of driftwood (140 pieces) accumulated at the bridge, the water overflowed the banks and the flood-flow depth was H_f=2.0cm (right bank and left bank). This implies that the increase of the driftwood projected area resulted in the increase in the blockage ratio A/A_b of an obstruction in Main-channel (see Fig.8).

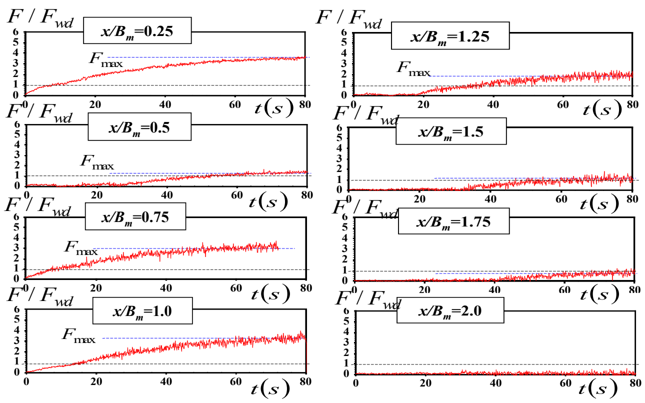

Fig. 9 Time series of drag force exerted on the model house on flood plain

Flood Damage to House around Bridge

To examine the flood damage to house around a bridge by flood flow, we measured the drag force exerted on the model house. Figure 9 shows the time series of the drag force exerted on the model house (right bank). The drag force values are normalized by the Wooden house demolitions criteria F_{wd}. A wooden house is broken when the drag force per meter reaches over 1.06 tf/m (Koshimura & Kayaba (2011)). By using scale ratios (1/80: model house), we calculated the Wooden house demolitions criteria F_{wd}.

At time t=0(s), the flood-flow reaches the house on the floodplain and drag force is exerted on the house.

The drag force values (x/B_m=0.25) increase with time and exceed the Wooden house demolitions criteria (F_{max}/F_{wd}>1.0) at time t=8.0(s). The drag force values reach the maximum value F_{max} at t=70.0(s).

The maximum value of the drag force F_{max} decreases significantly at x/B_m=0.5 and increases again for $x/B_m \geq 0.75$. This implies that the detour flood-flow flows around the side of the house at x/B_m=0.5 (Fig.10).

The drag force values exceed the Wooden house demolitions criteria (F_{max}/F_{wd}>1.0) for x/B_m=0.0-1.5 (right bank and left bank, Fig.10). This indicates that the wooden house is broken and washed away in the region of x/B_m=0.0-1.5 on the right bank and left bank. The drag force becomes negligibly small for $x/B_m \geq 2.0$ and the house is at little risk of flood hazard in this region.

CONCLUSION

In the present study, three kinds of flume experiments (1. Pitching moment measurement of driftwood, 2. Driftwood accumulation experiment, 3. Drag force (exerted on the model house) measurement) were performed to investigate the log jam formation around a bridge and flood damage to a house by a detour flood flow in a blocked river. Main findings are as follows:

1. The pitching moment stability is greatly affected by the gravity center position of driftwood. When the gravity center position is the upstream edge of the driftwood, the driftwood is floating at $\alpha < 0°$ (negative angle of attack) and the projected area of driftwood in flood flow becomes larger.

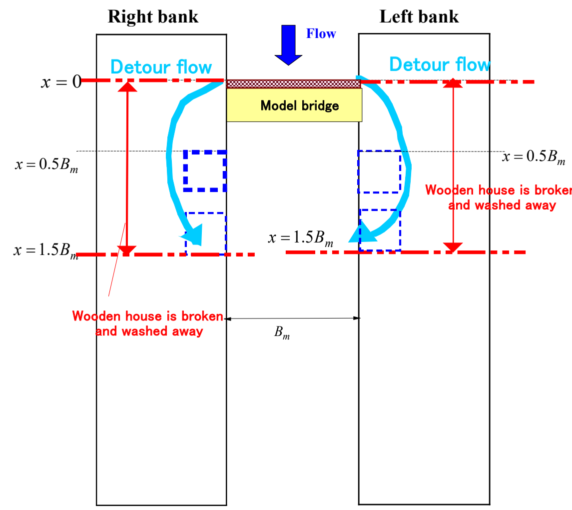

Fig. 10 Time series of drag force exerted on the model house on flood plain

2. The results of Driftwood accumulation experiment revealed that a blocking probability of driftwood at the bridge is determined by the projected area of driftwood. When the gravity center position was the upstream edge of the driftwood, the water overflows the banks. The increase of the driftwood projected area resulted in the increase in the blockage ratio A/A_b of an obstruction in Main-channel.
3. We investigated the flood damage to a house around a bridge by flood flow in a blocked river. The values of the drag force exerted on the model house are larger than the Wooden house demolitions criteria for x/B_m=0.0-1.5. The drag force becomes negligibly small for $x/B_m \geq 2.0$ and the house is at little risk of flood hazard in this region.

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