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## Flume experiments on log accumulation at the bridge with pier and without pier

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**Abstract.** Heavy rain causes landslide and debris flow, which produce sediment and woody debris in the mountain river basin. During the process, woody debris and sediment are trapped by the obstacles. As a result, woody debris accumulations at bridges are formed. Trapped woody debris at the bridge caused inundation because the obstacle blocked the water flow in the river course. To get more information regarding the woody debris accumulation at a bridge, laboratory flume was used for experiments to investigate the characteristics of woody debris accumulation at a model bridge without a pier. As a result, the experiments show that the number of trapped wood pieces increases with the number of released pieces. Moreover, the trapped wood pieces caused wood accumulations at the model bridge and backwater rise in its upstream side region. Besides that, the backwater rise increase with a number of trapped wood pieces at the bridges.

### 1. Introduction

Heavy rain hit Tsuwano Town in Shimane Prefecture and Hagi City in Yamaguchi Prefecture on July 28, 2013. It caused landslides and debris flows in the mountain areas of the Nayoshi river basin in Tsuwano Town. These resulted in the flood with a significant amount of woody debris and sediment in the Nayoshi River.

Woody debris accumulation has possibilities to cause chronic problems such as backwater rise, overflow during heavy rain, and as a result, it may change the river course as shown in figure 1. It is important to know the characteristics of woody debris accumulation at a bridge from the viewpoint of flood defense.

Laboratory flume experiments on woody debris in the <sup>6</sup>team have been made in the previous works. For example, the wood transport mechanism research and the characteristics of the bridge and the woody debris had a significant effect on woody debris accumulation during the flood event in Switzerland in 2005 [1-5]. However, more studies are needed in order to obtain a deeper understanding of the log accumulation at the bridges.

The purpose of this study is to investigate the characteristics of log accumulation at the bridge based on laboratory flume experiments. In the present study, logs are assumed representative of woody debris in rivers. Flume experiments are carried out in order to observe the behavior of log accumulation at a model bridge.

In the experiments, we used some video cameras as the records. Then, by using the videos, we observed the behavior of log accumulation at a model bridge. Moreover, depth was measured after the arrival of the wood pieces at the model bridge. Finally, wood pieces trapped at the bridge were counted.



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From these observations, we found two characteristic phenomena; wood accumulation and backwater rise. Moreover, we discussed the loss coefficients due to wood accumulation and a model bridge.



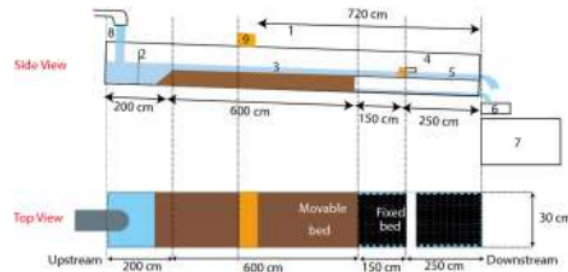
**Figure 1.** Woody debris accumulation at the bridge.

## 2. Flume experiments

### 2.1. Experimental apparatus

#### 2.1.1. Laboratory flume.

In the experiments, the rectangular flume was used, as shown in figure 2. It is 12 m long and 30 cm wide. A model bridge without piers was installed at the station 2.5 m upstream from the downstream end. The length of the model bridge was 30 cm; the width of the model bridge was 5.2 cm.



**Figure 2.** Laboratory flume: (1) Flume; (2) Filter; (3) Movable bed; (4) Model bridge; (5) Fixed bed; (6) Trap; (7) Water tank; (8) Inflow of clear water; (9) Basket for wood supply.

#### 2.1.2. Wood pieces.

Two kinds of mixtures of cylindrical wood pieces were used as a model of woody debris; one is the mixture of wood pieces of the length 7.0 cm and the diameter 2.0 mm and the other is the mixture of wood pieces of the length 3, 4, 5, 6, 7, 8, 9, 10, 11 cm and the diameter 2.0 mm. The wood condition is shown in table 1 'Case 1' indicates the mixture of uniform pieces with the same length and 'Case 2' indicates the mixture of mixed pieces with a different length.

**Table 1.** Model wood condition.

Wood Pieces	Case 1		Case 2	
Length (cm)	7	3,4,5,6,7,8,9,10,11	7	3,4,5,6,7,8,9,10,11
Diameter (mm)	2	2	2	2
Total number of released wood pieces	405	405	405	405

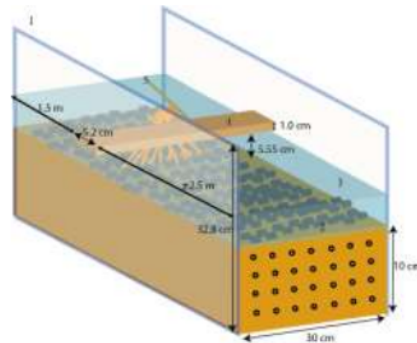
Trapping wood pieces at the model bridge requires a sufficient number of released wood pieces. Based on the previous experiments, the critical condition for trapping wood pieces by the model bridge was around 200 pieces. Therefore in total 405 wood pieces were released in the present experiments.

In order to maintain the waterlogged condition, the wood pieces were soaked in the water for 10 minutes and then were put in a basket for wood supply. The density of the wood pieces was  $0.65 \text{ g/cm}^3$ .

The prototype of the model wood was based on field investigations. The model wood conditions were determined in order to maintain the similarity between the model in the laboratory and the prototype in the field. The woody debris deposited in the field has branches and roots. However, for simplicity, the present experiments used cylindrical wood pieces as a model of woody debris. This satisfies the condition of  $L \gg D$ .

### 2.1.3. Model bridge

Referring to Miyanokami Bridge, we made a bridge model for experiments. Figure 3 shows the bridge model in the laboratory flume. The length of the bridge model was 30 cm; the width of the bridge model was 5.2 cm; the thickness of the bridge model was 1 cm. The bridge model was set 2.5 m from the downstream end.



**Figure 3.** 3d image of the bridge in the flume experiment fixed bed part.

### 2.2. Experimental procedure

Referring five video cameras were installed at three positions: the first video camera at the downstream end was for measuring flow discharge; the second one on the top of the flume was for recording the movement of the wood pieces; the third and fourth ones at the right-hand side of the flume were for recording the movement of the wood pieces and the longitudinal profile of water flow; the fifth video camera was for taking the view of the model bridge from the upstream side. Several buckets for the measurements of flow discharge were prepared at the downstream end.

Trapping wood pieces at the model bridge without a pier requires water flow surface contact with the bridge. Therefore, the experimental procedure for the model bridge without a pier is described as follows:

- First, water flow was supplied at the upstream end of the flume.
- The water depth on the model bridge was measured after the confirmation of the steady flow.
- The model wood pieces were instantaneously released on the flow surface at the station 7.2 m from the downstream end. Some wood pieces were trapped at the model bridge and the others were transported to the downstream end.
- Flow discharge and depth were measured during the accumulation of wood pieces at the model bridge. During this measurement, the flow situation has to be in the steady-state.
- The wood pieces which arrived at the downstream end were counted.

**Table 2.** Experimental condition.

Case No.	Case 1	Case 2
Bridge pier	With a pier	Without a pier
Bridge scale	1/120	1/120
Flume slope	0.6/100	0.6/100
Flow discharge (cm <sup>2</sup> /s)	200	300

**3. Results and discussion**

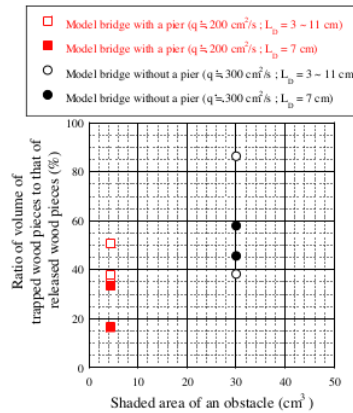
*3.1. Log accumulation*

Figure 4 illustrates the accumulation of wood pieces trapped by the model bridge without a pier in the experiment. The mixed wood pieces of different lengths were used as the model of woody debris. In the case of the model bridge without a pier, simultaneous contact of a flowing log piece with the bridge deck and the flume bed is required for the initial log accumulation.

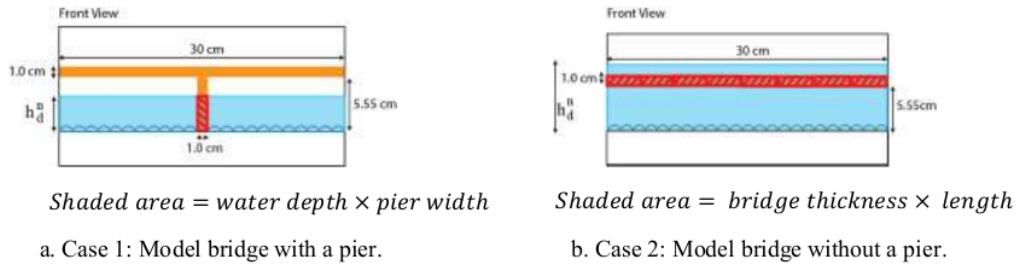
The research conducted that introduced the shaded area of an obstacle, such as the bridge [8,9]. By plotting the volume ratio of trapped pieces to released pieces versus shaded areas of the model bridge, it is able to find that volume ratio of the trapped pieces increases with the shaded area of an obstacle as shown in figure 5. Furthermore, the volume ratio of trapped pieces to the released pieces in the cases of the mixed pieces and the uniform pieces are compared. The result shows less difference. The volume ratio of trapped pieces to released pieces increases with the total shaded area of the obstacles as shown in figure 6.



**Figure 4.** Side view of wood accumulation and backwater rise at the model bridge without a pier.



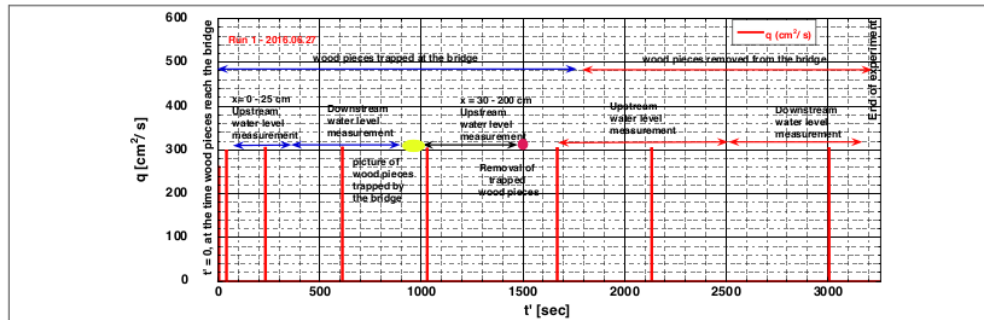
**Figure 5.** The ratio of the volume of trapped pieces to released pieces versus shaded area.



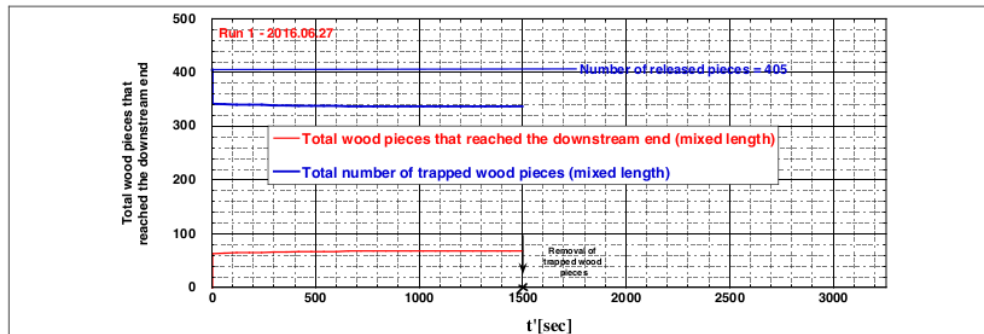
**Figure 6.** The definition of the shaded area of model bridges.

**3.2. Water flow discharge and number of trapped pieces at the bridge**

The time change in flow discharge is shown in figure 7. We can find that the flow discharge is almost constant except for the first measurement. This flow discharge measurement is done eight times through the experiment. The flow discharge measurement started at some time after wood pieces reached the model bridge. The second measurement at the 30 seconds after the wood pieces reached the model bridge. The third measurement is done during the upstream water level measurement from  $x'=0$  to  $x'=24$ . The fourth measurement is done during the downstream water level measurement. The fifth measurement is done during the measurement of the upstream part from  $x'=30$  to  $x'=200$ . The sixth measurement is done 1 minute after removal of the wood pieces from the model bridge. The seventh measurement is done during the measurement of the upstream water level. The eighth measurement is done during the measurement of the downstream water level.

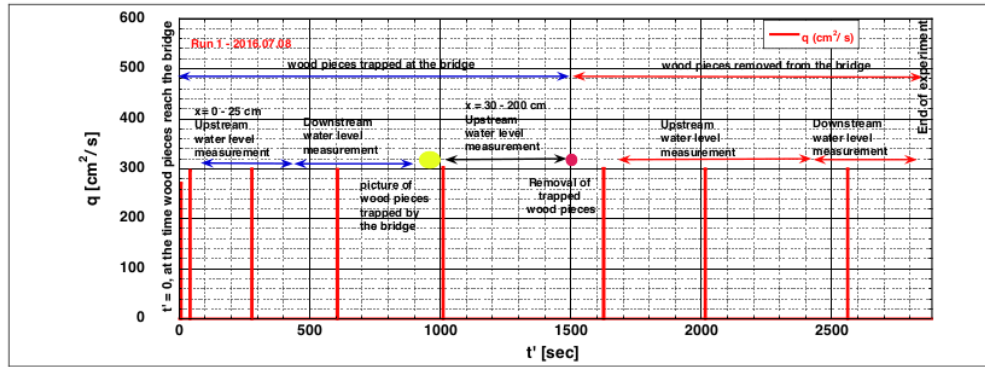


**Figure 7.** Hydrograph of flow discharge for wood pieces with mixed length.

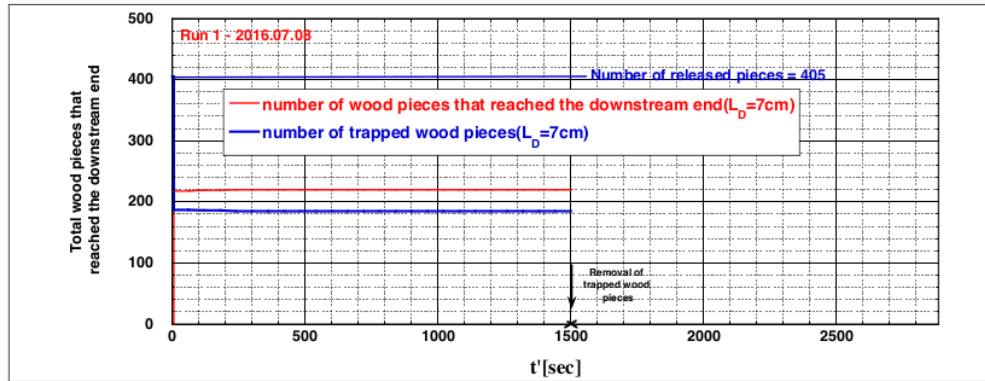


**Figure 8.** The total number of wood pieces that reached the downstream end and that of wood pieces trapped by the model bridge (mixed length).

The time change in flow discharge for wood pieces with a length of 7 cm is shown in figure 9. We can find that the flow discharge is almost constant except for the first measurement. This flow discharge measurement is done in the same timing as the experiment which using a mixed length of 3, 4, 5, 6, 7, 8, 9, 10, and 11 which has been explained above.



**Figure 9.** Hydrograph of flow discharge for wood pieces with a length of 7 cm.



**Figure 10.** The total number of wood pieces that reached the downstream end and that of wood pieces trapped by the model bridge (7 cm).

During the water depth measurement during wood accumulation at the bridge, we also catch and count the wood pieces which arrived at the downstream end of the flume. Figure 8 and figure 10 show a change in the total number of wood pieces which arrived at the downstream end of the flume for both mixed cases and 7 cm wood pieces cases. Using this measurement we estimated the total number of wood pieces trapped by the model bridge. Figure 8 and figure 10 also show a change in the total number of wood pieces trapped by the model bridge. After an uncertain time, the total number of wood pieces that reached the downstream end become zero. From these figures, it is found that after a certain time the total volume of trapped wood pieces will stay steady.

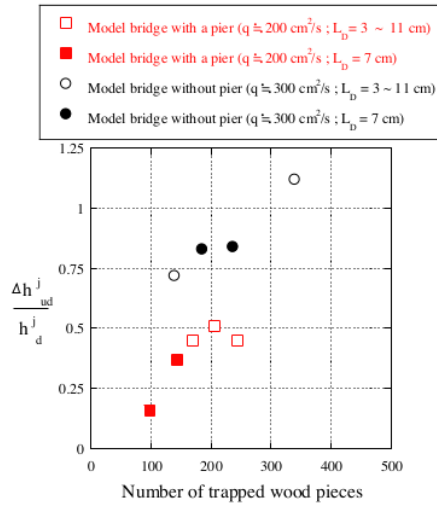
### 3.3. Backwater rise

The log accumulation at the model bridge generated a significant backwater rise. However, approximately the same water level can be found at the downstream side of the model bridge. In order to calculate the backwater rise, the following equation 1.

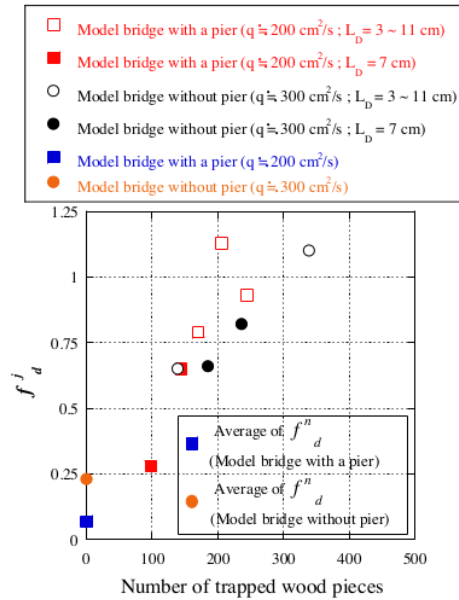
$$\Delta h_{ud}^j = h_u^j - h_d^j \tag{1}$$

where  $h_u^j$  = upstream water depth with log accumulation;  $h_d^j$  = downstream water depth with log accumulation.

Figure 11 presents the backwater rise based on equation 1 versus the volume of wood pieces trapped by a model bridge. It is found that the backwater rise increases with the volume of trapped wood pieces.



**Figure 11.** Relationship between the backwater rise and the volume of wood pieces trapped by model bridges.



**Figure 12.** Relationship between the loss coefficient and the number of wood pieces trapped by model bridges.

### 3.4. Loss coefficient

Head loss due to obstructions in a river can be expressed by ‘loss coefficients’. ‘Loss coefficients’ due to wood accumulation and a model bridge can be defined by equation 2 and equation 3.

$$f_d^j \equiv \Delta E_{ud}^j / ((v_d^j)^2 / 2g) \tag{2}$$

$$f_d^n \equiv \Delta E_{ud}^n / ((v_d^n)^2 / 2g) \tag{3}$$

where  $f_d^j$  = loss coefficient with wood accumulation;  $f_d^n$  = loss coefficient without wood accumulation;  $v_d^j$  = downstream velocity with wood accumulation;  $v_d^n$  = downstream velocity without wood accumulation;  $\Delta E_{ud}^j$  = energy loss between the upstream and downstream station of the model bridge with wood accumulation;  $\Delta E_{ud}^n$  = energy loss between the upstream and downstream station of the model bridge without wood accumulation.

Figure 12 shows loss coefficients versus the volume of trapped wood pieces at the model bridge. It is found that the volume of trapped wood pieces determines the loss coefficients. Therefore, it becomes important to predict the volume of wood pieces trapped at a bridge from the viewpoint of flood defense.

The loss coefficient in the case without trapped wood pieces depends on the bridge characteristics. However, as the volume of trapped pieces increases, the dependence of loss coefficients on the volume of trapped pieces becomes larger.

#### 4. Conclusions

- The volume ratio of trapped pieces to released pieces increases with the total shaded area of the obstacles.
- After a certain period of time, the flow will stay steady, and total trapped wood pieces will not change drastically.
- From several measurements of flow discharge, it is found that the first measurement decreases, which was at the time of blockage formed at the bridge.
- The backwater rise increases with the volume of trapped wood pieces. Therefore the volume of trapped wood pieces determines the backwater rise at the model bridge.
- The loss coefficients increased with the volume of wood pieces trapped by the model bridge. Thus the volume of trapped wood pieces determines the loss coefficient.

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