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Flume Experiments on Wood Debris Jam at an Arch Bridge in Upstream River Reach during Flash Flood

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Abstract During our field surveys, two types of woody debris deposition were found. One is deposition of individual wood pieces and the other is formation of woody debris jams at obstructions such as a bridge. To investigate behavior of wood debris jam at a bridge, a series of flume experiments was performed in a smooth acrylic rectangular flume. A model of an arch bridge was used as an obstacle in river. The arch bridge was based on Yoriguci bridge. Wooden cylinder was used as model of wood debris. An interpretation of experimental results shows that the wood debris jam can be determined by number of released wood pieces and shaded area of obstructions. These experimental results also reveal that wood debris jam formed by the model bridge contribute to backwater rise. From investigation on flow around model bridge, it is clearly shown the presence of backwater rise caused by the number of wood pieces trapped by a model of an arch bridge. The results also show that the loss coefficient depends on trapped wood pieces. A simple procedure was proposed in this study which seem to provide for predicting backwater rise due to wood debris jam at obstructions.

Keywords: Wood Debris, Arch Bridge, Jam, Backwater Rise.

INTRODUCTION

A heavy rain caused landslides and debris flows along the upstream river reach in the mountain area. These resulted in flood with a significant amount of sediment and wood. (e.g. [1,2]). The transported wood accumulated at structures in rivers such as Yoriguchi Bridge. Yoriguchi Bridge is an arch bridge. The other wood overflowed the banks at several section then deposited on field, in riparian trees and at bridge. Two types of wood debris deposition [1] : deposition of individual wood pieces and formation of wood debris jams. The wood debris jams were on field and at bridges. There are two types of wood debris jams occurred in riparian trees [2]. The jam formed by a single tree or utility pole and the jam formed by two or more different trees.

A number of flume experimental studies and field investigationshave been conducted in terms of geomorphology and river engineering to investigate the behavior of wood debris in river and floodplain. (e.g. [1-9]). For example: the probability of formation of wood jam in river depends on Length of wood pieces, the characteristics of obstacles and Froude Number [1-9]. Length of individual wood debris increase the probability of formation of wood jam in river with complex morphology [2]. The freeboard, the approach flow Froude number and the bridge characteristics in rivers were influenced significantly on the probability of wood jam at bridge decks [3]. Wood pieces tend to deposit on the outside of bends, at islands and bars head, in floodplain forests and large boulders as individual wood pieces [1]. Riparian vegetation and boulders can also become obstructions for longer wood pieces [1]. There are two classes of wood debris jam observed at bridge: single – pier jam and span blockage [9].The accumulation or jam at bridge also caused backwater rise [2, 3, 9]. The jam blocked the channel and produced backwater rise. Backwater rise due to the jam at a bridge from the view of river engineering has emerged as an important issue for flood disaster prevention and reduction. However, few researchers have addressed the problem of backwater rise due to wood debris jam at an arch bridge during flood event. The purpose of the present paper is to investigate formation of wood debris jam at a model of archbridge and its effect. Wood debris pieces are assumed representative of floating wood debris in river during a flash flood.

METHODOLOGY

Model of hydraulics

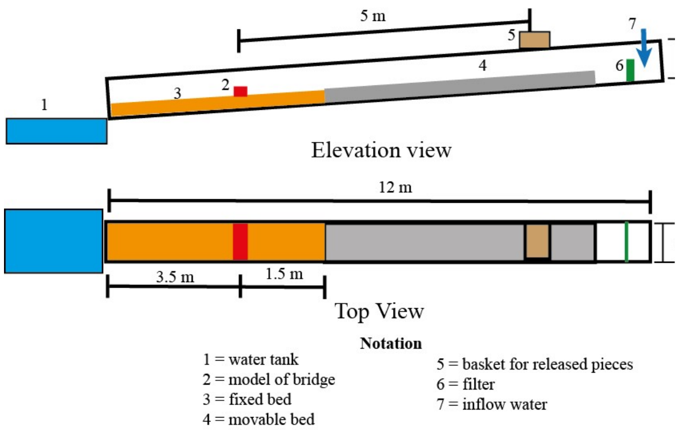
The flume experiments described in this study were performed in a rectangular flume with smooth acrylic board on both the lateral sides was used for laboratory flume experiment. The flume was 30 cm wide, 32.8 cm high and 12 m long. Fig. 1 highlights the schematic diagram of the flume.

The bed slope of the flume was set at 0.6/100 and divided by two part: movable and fixed parts. The bed material used in all tests consisted of sediment grains having a representative diameter d_{50}=3.6 mm and a density of ρs=2650 kg/m^3. The movable and fixed bed parts were composed of homogeneous sediment grains.

An arch bridge was used as an obstruction and placed on the fixed bed part 2.5 m distance from the downstream end. Pieces of wooden cylinders were used as a model wood pieces. The apparatus for dropping the wood pieces on the flow surface was installed at the station 5 m upstream from the model bridge. Inflow flow rate per unit width was about q=200 cm^2/s or 250 cm^2/s at the upstream end.

Model of bridge

A model bridge with smooth acrylic board was used in the flume as shown in Fig. 1. The model is an arch bridge that based on Yoriguchi Bridge. Its reduced size of the prototypes were 1/140 for arch bridge.River slope was 0.6/100 near Yoriguchi Bridge.



(a)

(b)

FIGURE 1. (a) Schematic Feature of Experimental Flume, (b) A Side Photo of Experimental Flume

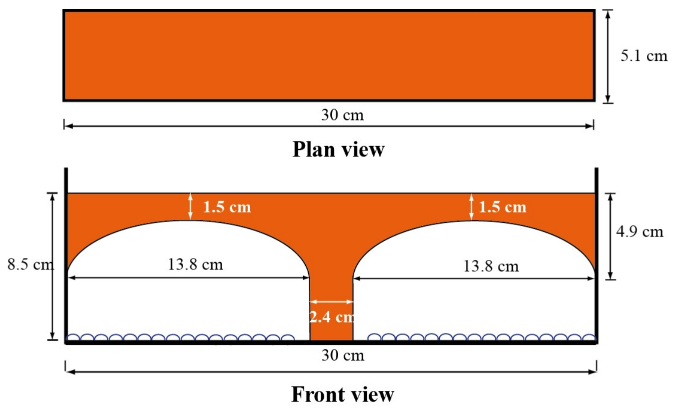


FIGURE 2. Schematic Figure of Arch Bridge

Model of wood pieces

Model of wood pieces was simulated by a cylindrical wood pieces with diameter D = 2.0 mm and length L=7.0 cm (Fig. 3b). The wood dimension was corresponded to the wood pieces used in [4].This satisfies the condition of L>>D. Before the model of wood pieces put in a basket, the pieces were soaked in water for 10 minutes. The density of wood pieces was 0.65 g/cm^3. By openning the bottom of the basket as shown inFig.3a, the pieces was released on water surface. The number density of the pieces was 100 pieces / (30cm*13cm) or 200 pieces / (30cm*13cm).

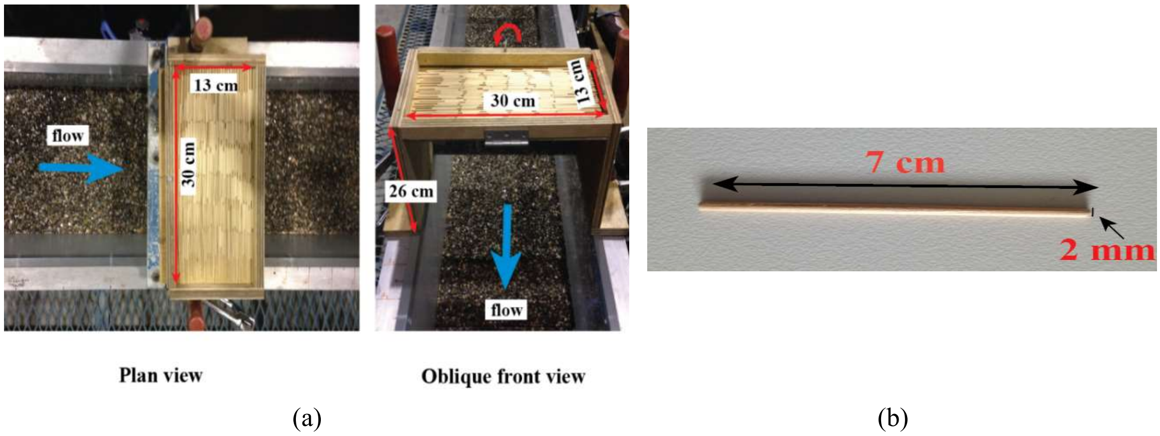


FIGURE 3. (a) A Basket for Released Wood Pieces , (b) A Cylindrical Wood Pieces

FIGURE 4. Front View of Wood Jam at The Model Bridge

Test procedure

Our experimental set up bears a close resemblance to the one proposed in [5]. Mixed flow of sediment and water occurred during clear water was supplied from the upstream flume end. The flow transported downstream along the bed of flume. The flow was also almost clear because less sediment carried out by the mixed flow. 1 minute after the arrival of flow front at the model bridge the flow almost steady state.

Model of wood pieces in the basket were released on the flow surface of steady and unifom flow. The congested wood pieces moved to the model bridges in the flume. The model bridge trapped wood pieces and formed a jam (Fig. 4). The other passed through the bridge. In general, flow discharge is calculated by multiplying the area of water in a cross-section area by the average velocity of the water in that cross section. In this study, flow discharge was measured by catching the outflow water ina few containers at the downstream end.

The water depth and the behavior of wood pieces at model bridges were recorded continuously by four video cameras that placed in the vicinity of the flume. The first video camera was put on the top of the flume. The second and third video cameras were installed on the right and left-hand flume side. The fourth video camera was set up near the downstream flume end.

Table 1 provides the experimental condition. Fifteen runs were performed. The duration of each run was around 15 minutes.

TABLE 1. Experimental Condition

No	Slope	Discharge	Distance between model bridge and basket	Number of released pieces
1	0.6/100	253.58	5	400
2	0.6/100	256.22	5	200
3	0.6/100	260.33	5	400
4	0.6/100	225.92	5	550
5	0.6/100	261.25	5	300
6	0.6/100	254.87	5	600
7	0.6/100	185.67	5	800
8	0.6/100	219.63	5	400
9	0.6/100	263.32	5	400
10	0.6/100	208.33	5	600
11	0.6/100	187.58	5	800
12	0.6/100	235.96	5	800
13	0.6/100	245.34	5	600
14	0.6/100	187.31	5	700
15	0.6/100	194.56	5	500

Measurement of water level

Fig.5 shows the x and y coordinates. The x coordinate is in the flow direction. The water surface level measures by point-gage at y=15 cm for the longitudinal depth profile and at x=-5cm and (B+5cm) for the transverse depth profile.

Water surface levels were measured under two different conditions; with wood debris jams and without wood debris jams at the model bridge. Therefore, backwater rise Δh includes the effect of wood debris jams and model bridge in the first stage and that of bridge only in the second stage.

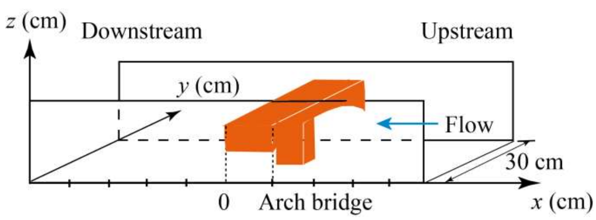
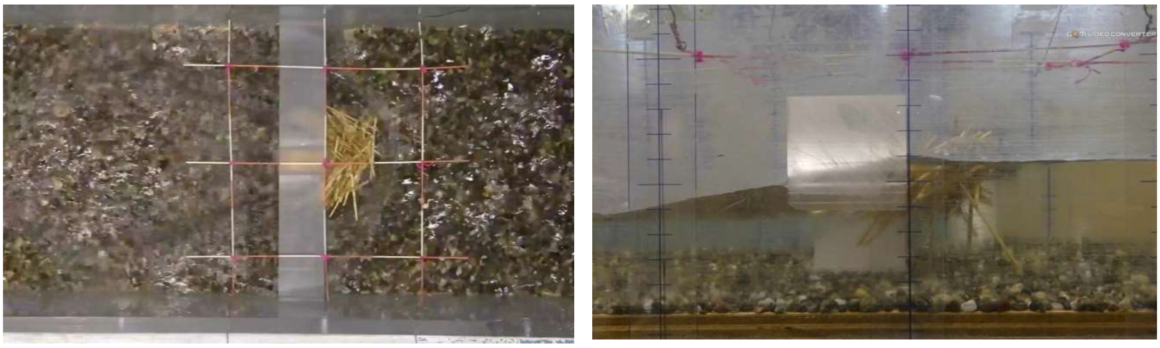


FIGURE 5. Definition Sketch of the x, y and z Coordinates Near The Measurement Point

Measurement of quantity of wood debris jam

The number of wood pieces trapped and accumulated at the model bridge was counted during and after the experimental runs. The volume of wood jam was calculated by multiplying the bottom area of jam by the average of height of jam.



(a) (b)

FIGURE 6. (a) A Top View of Wood Debris Jam at The Model Bridge, (b) A Side View of Wood Jam at A Model Bridge

EXPERIMENTAL RESULT AND DISCCUSSION

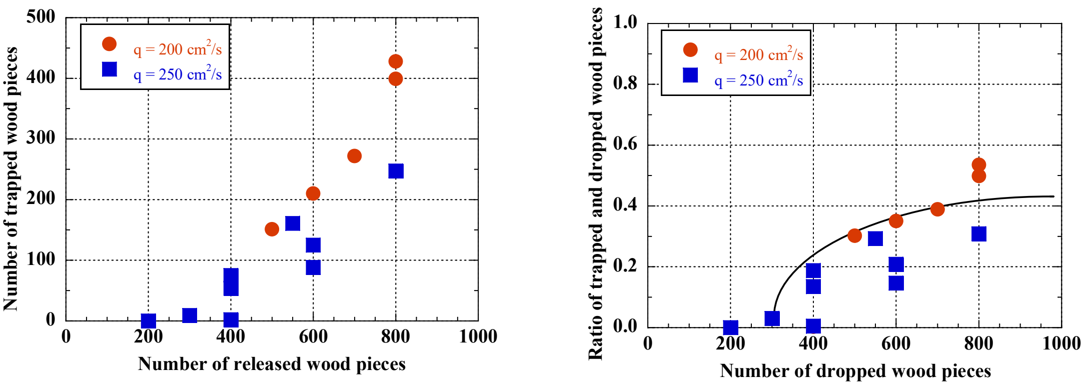
One of the main goals of this experiment was to attempt to find a way to predict backwater rise that occurred when woody debris pieces trapped by model bridge. These results both negate and support some of the previous research [5]. It was proposed that backwater rise was influenced by the volume of the wood debris jam.

Wood debris jam at the model bridge

A wood debris jam at the model bridge can determined by number of released wood pieces (Fig. 6). Fig. 6 shows wood jam occurred after wood pieces met the model bridge. The number of trapped pieces depended on dropped pieces. Fig. 7 presents the number of released pieces increase significantly with the number of trapped pieces. Trapping pieces by the model bridge requires sufficient number of pieces dropped on the flow surface. Critical condition for trapping the pieces by the arch bridge is N_c=300. Here N_c denotes the number of released pieces in the critical condition. A shaded area of obstruction was calculated to compare with apparent volume of wood debris jam (Fig. 9)

Arch bridge

Fig. 8 presents the backwater rise grows significantly with the number of trapped wood pieces at arch bridge. The downstream water depth with jam is approximately equal to the normal depth. For convinience, the normal depth and velocity can be used as a reference value.



(a) (b)

FIGURE 7.(a) Relationship Between The Number of Released Wood Pieces and The Number of Trapped Pieces, (b) Relationship Between The Number of Released Wood Pieces and Ratio of Trapped and Released Pieces.

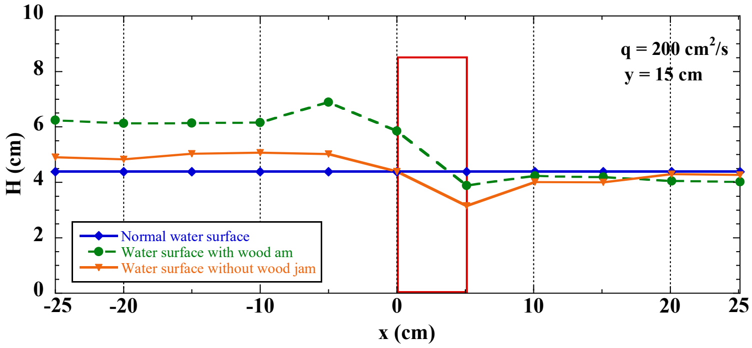


FIGURE 8. Measurements of water level with and without woodjam atmodel bridge

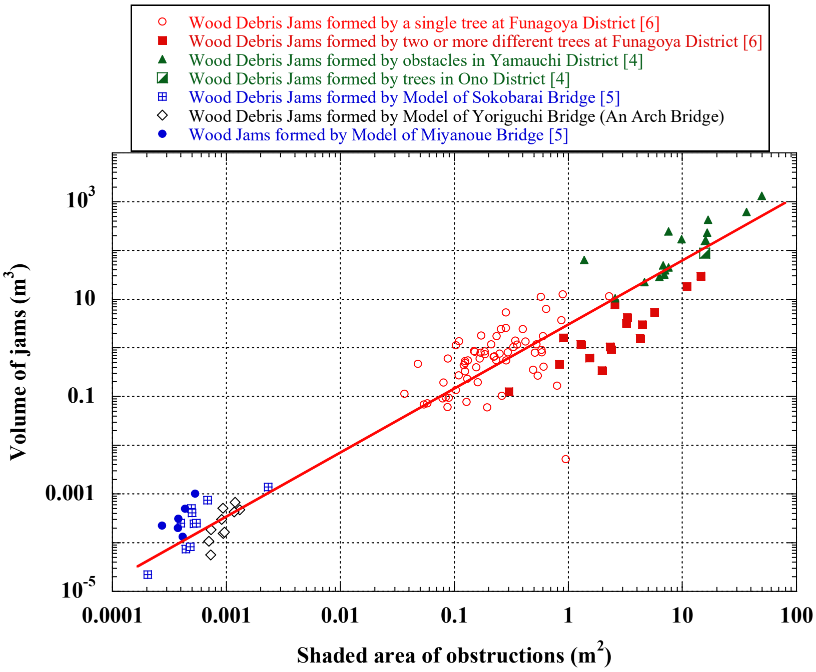


FIGURE 9. The Relationship Between the Shaded Area of Obstructions and The Volume of Wood Debris Jam

Backwater rise and loss coefficient due to wood debris jam

Every water level is approximately similar at around x=10 cm and backwater rise caused by the wood debris jam at the model bridge is significantly large. Froude Number was also calculated and plotted in Fig. 9a. The following equations for calculating backwater rise and loss coefficient that proposed in [3] were used. Fig. 9b presents the backwater rise grows significantly with the number of trapped wood pieces. The downstream water depth with jam is approximately equal to the normal depth. For convinience, the normal depth and velocity can be used as a refference value.

Backwater rise due to wood debris jam

to identify backwater rise, the following equations that introduce in [3] were used

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

$$\Delta h_{ud}^{n} = h_u^n - h_j^n \tag{2}$$

where $h^j{}_u$ = upstream water depth with jam; $h^n{}_u$ = upstream water depth without jam: $h^j{}_d$ = downstream water depth with jam and $h^n{}_d$ = downstream water depth without jam

Loss Coefficient

Loss coefficients due to log jam at a bridge [3] can be defined in the following equation:

$$f_d^j = \Delta E_{ud}^j / \left((v_d^j)^2 / 2g \right) \tag{3}$$

$$\Delta E_{ud}^j = \left\{ \frac{(v_u^j)^2}{2g} + h_u^j \right\} - \left\{ \frac{(v_d^j)^2}{2g} + h_d^j \right\} \tag{4}$$

$$v_u^j = q / h_u^j \tag{5}$$

$$v_d^j = q / h_d^j \tag{6}$$

Where $f^j{}_d$ = loss coefficient with jam; $v^j{}_u$ = upstream velocity with jam; $v^j{}_d$ = downstream velocity with jam and $\Delta E^j{}_{ud}$ = energy loss between the upstream and downstream station of the model bridge with jam

The loss coefficient is plotted against the number of trapped wood pieces at model bridge in Fig. 11. This figure represents the loss coeffisient due to wood jam at model bridge and indicates loss coefficient depends on trapped wood pieces. This figure shows loss coefficient increases with the number of trapped pieces. The loss coefficient can be estimated by the figure. However, the information of the number of trapped wood pieces in the field is difficult to obtain. Since the number of trapped of wood pieces correspond to volume of jam, the apparent volume of wood jam can be used to estimate the loss coefficient. A procedure as shown in Fig. 12 to predict backwater rise.

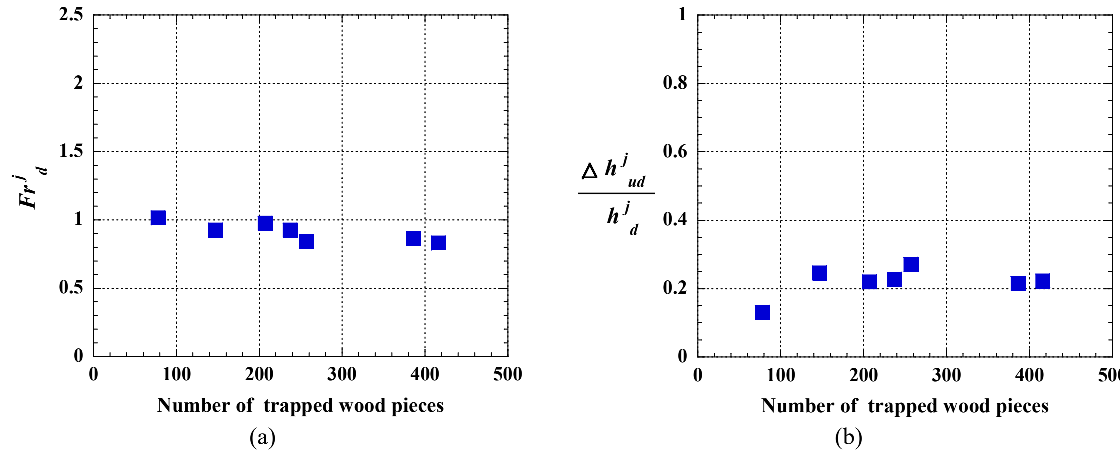


FIGURE 10. (a) The Relationship Between the Number of Trapped Wood Pieces and Froude Number, (b) The Relationship Between The Number of Trapped Wood Pieces and Ratio of Backwater Rise

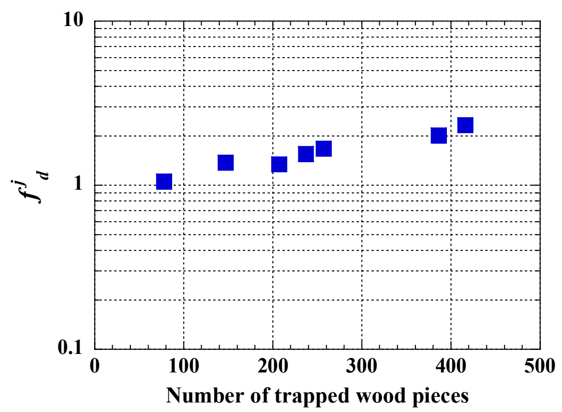


FIGURE 11. The Relationship Between the Number of Trapped Pieces and Loss Coefficient

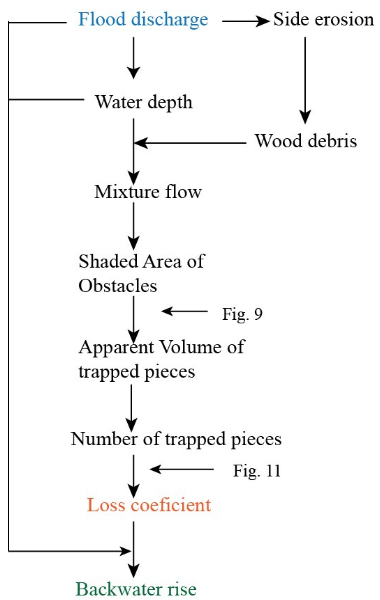


FIGURE 12. A Simple Procedure for Predicting Backwater Rise

CONCLUSIONS

The analysis of experimental data shows that a wood debris jam at the model bridge can determined by two factors: one is number of released wood pieces and the other is shaded area of obstacles. Dependence of backwater rise on the number of wood pieces trapped by a model of an arch bridge is clearly shown. The loss coefficient increases significantly with the number of trapped wood pieces. A simple procedure for predicting backwater rise was proposed. This study neglects the fine material such as branches and leaves. The next stage of study should be extended to the mixed materials of branches and leaves.

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