AN INVESTIGATION OF MEASURES AGAINST WOODY DEBRIS THROUGH HYDRAULIC MODEL EXPRIMENTS

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ABSTRACT

The woody debris cause damage: for example, rising water levels and floods when they jam at bridges; or sudden surges in water levels downstream when they catch temporarily on building structures and standing trees, then break away. This study is based on a flume experiment that investigated how damage caused by the woody debris, as described above, is affected by the shape and provenance of the wood, as well as by debris volumes and water flow. In addition, the study investigated measures against woody debris, using hydraulic models that reproduced actual landforms. The main findings are as follows. (1) When logs carried along by debris flows passes through a forest area, they get stuck, the sediment and woody debris trapping that follow. This causes temporary blockages of mountain rivers. (2) The peak discharge that occurs after the blockages collapse is around 1.2 times higher than that of the debris flow itself. (3) Based on an analysis of woody debris flow in existing river channels, when traps are installed on the sedimentation section of sabo dams in a form that does not cut across the channel, logs can be stopped without obstructing the flow of debris.

Key words: Hydraulic model experiment, Woody debris, Debris flow, Sabo dams

INTRODUCTION

With as much as 65% of its national territory covered by forest, Japan is subject to disasters in downstream areas caused by rain-induced landslides and debris flows, as well as flows of sediment produced by bank erosion. To prevent such disasters, facilities including sabo dams have been built. However, in recent years, in addition to sediment, logs have been carried down rivers in great quantities, causing increased damage in downstream areas.

Up until now, damage caused by woody debris has been thought to be limited to impacting of structures and raised water levels or flooding caused by accumulation of logs at bridges (Mizuyama, *et al.* 1991). Judging from the results of past experiments related to woody debris, woody debris in a river with a straight channel and no changes in flow width cause hardly any change in velocity and water depth. However, woody debris in a river that curves, or in a river trough whose width changes, temporarily block debris flow, causing a great change in velocity and water depth, and this can be a cause of greater damage (Mizuyama, *et al.* 1988).

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investigate differences in the water depth, velocity, discharge, and flow concentration of debris flow, depending on whether or not they contained woody debris, Japan

In this study we changed the width of a straight channel, and conducted experiments to possible countermeasures for outflows of logs are (1) prevention of production at the collapse site, (2) prevention of tree destruction along the path of debris flow, (3) preventing destroyed trees from getting into rivers, and (4) woody debris trapping that float down debris flow (Mizuyama, *et al.* 1985). However, compared to countermeasures for sediment discharge, there is not much work being carried out. Therefore, we investigated countermeasures for woody debris by means of hydraulic model experiments that simulated the terrain of actual sites.

We carried out two kinds of experiments. Experiment 1 investigated the influence of woody debris on a debris flow with a straight flume. Experiment 2 was carried out to find an appropriate structures to trap woody debris efficiently with a physical model.

EXPERIMENT 1 (THE INFLUENCE OF WOODY DEBRIS ON A DEBRIS FLOW)

We confirmed the influence of woody debris on a debris flow, by conducting an experiment using a rectangular cross-section channel. Changes in the width of the channel caused the debris flow containing debris flow to grow bigger, even though there was only a small discharge (Hasegawa, *et al.* 2006). This is because the woody debris get mixed into the front part of the debris flow, where they get caught on protrusions and block the flow, forming a temporary obstruction of the river channel (hereinafter referred to as a temporary mountain-stream obstruction). However, because in the rectangular cross-section channel, the middle part of a woody debris is not at the point of impact with the protrusion, it is difficult for it to get caught, and presumably in a short time the situation becomes such that it is difficult for a temporary mountain-stream obstruction to form. In our experiment, to make it easy for the woody debris to get caught, and to recreate actual conditions in nature as accurately as possible, we used a trapezoidal cross-section channel. We focused our attention on the conditions under which protrusions cause a debris flow containing woody debris to form a temporary mountain-stream obstruction, and on the process of breakage of the obstruction, and studied changes in the discharge.

Outline of the experiment

Experimental conditions are shown in Table 1, and an outline of the experiment in Figure 1. To make the conditions of the channel easy to understand, we did not show the left-bank sidewall or trees. We used a straight trapezoidal cross-section channel that measured 10 cm in width, 700 cm in length and 20 cm in depth. It had a 15 degrees gradient and a sidewall gradient of 55 degrees. We raised the section of the channel 600 cm downstream by 10 cm to form a fixed-bed debris flow section, and put earth, sand and logs at a point 100 cm upstream.

Table 1 Experimental conditions

Case.	Sediment	Woody debris	Shape of the woody debris	Trees	Narrow width (cm)
1	S_1	nothing	-	nothing	-
2	S_1	existence	Type 1	nothing	-
3	S_1	nothing	-	existence	8
4	S_1	existence	Type 1	existence	8
5	S_2	nothing	-	existence	8
6	S_2	existence	Type 1	existence	8
7	S_1	existence	Type 2	existence	8
8	S_1	existence	Type 3	existence	8
9	S_1	existence	Type 1	existence	9
10	S_1	existence	Type 1	existence	7

As shown in Figure 2, we used two types of sediment: mixed sand (S1) with a maximum diameter of 20 mm, and an average diameter of 8.2 mm, and uniform sand (**S_2**) with an average diameter of 0.25 mm. We used three types of woody debris models, as shown in Figure 3: a thin, cylindrical type (**type 1**), a thick type (**type 2**) and a type with roots (**type 3**). In the case of setting up trees in the channel, we set them up 100 cm from the channel's downstream edge, and we changed the width of the narrow section during the course of the experiment. We carried out chronological measurement, using a collection box set up on a roller to measure the amount of sediment, discharge and woody debris flowing out of the downstream edge of the channel.

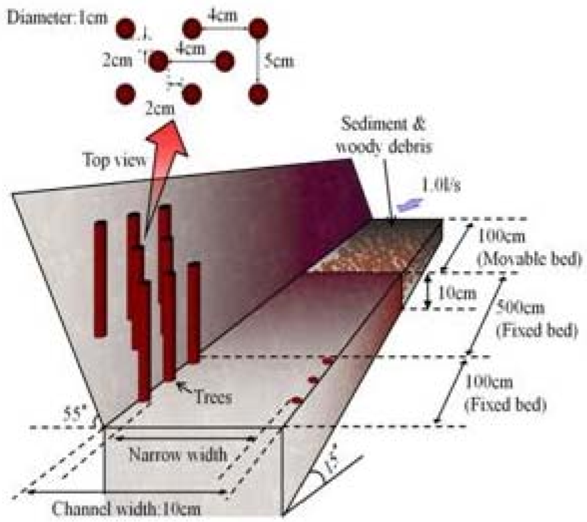

Fig. 1 Outline of the experiment

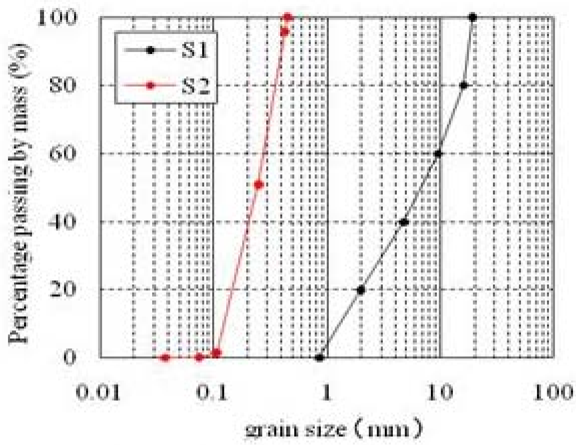

Fig. 2 Two types of sediment for the experiment

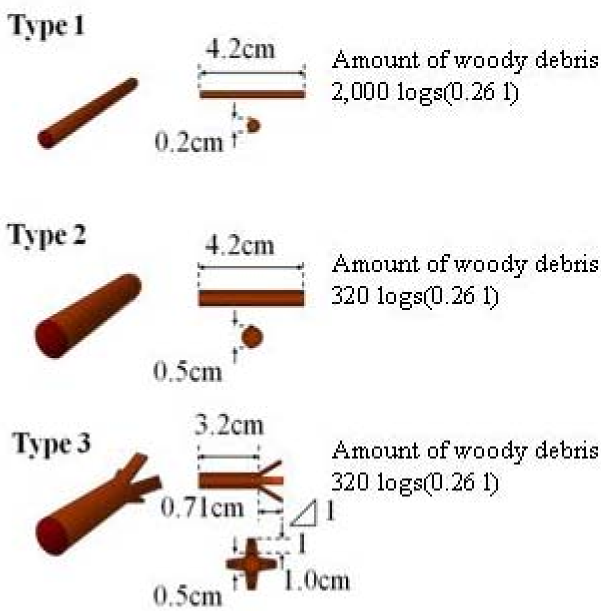

Fig. 3 Three types of woody debris models

Experimental results

Photo 1 shows images of the instant the debris flow passed the trees in experiments 3-8. t=0.0 sec is the time when the front end of the debris flow reached the trees. In case4 and 8, in which a temporary mountain-stream obstruction was formed, the woody debris became concentrated in the front part (t=0.0-1.0 sec). There were about 1,650 logs that reached the trees in case4, and about 300 in case 8. After the mass of woody debris reached the trees, some of the logs momentarily got caught on them, and at the same time, the debris was trapped over and over again in the narrow section, forming temporary mountain-stream obstructions up to 10-13 cm in height (t=0.5-1.0 sec). Because the flow of the logs was delayed right after the formation of an obstruction, the number of woody debris flowing out of the downstream edge of the channel was 1,286 in case 4, and 198 in case8. After the formation of an obstruction, since the debris moved upstream, it did not accumulate; because it overflowed the levee crown and flowed out swiftly, there was almost no decrease in mobility (t= 1.0-1.5 sec). Also, there was no flooding of the kind that can be seen on the sedimentation side of a large-scale landslide dam. The inflow discharge and the amount of

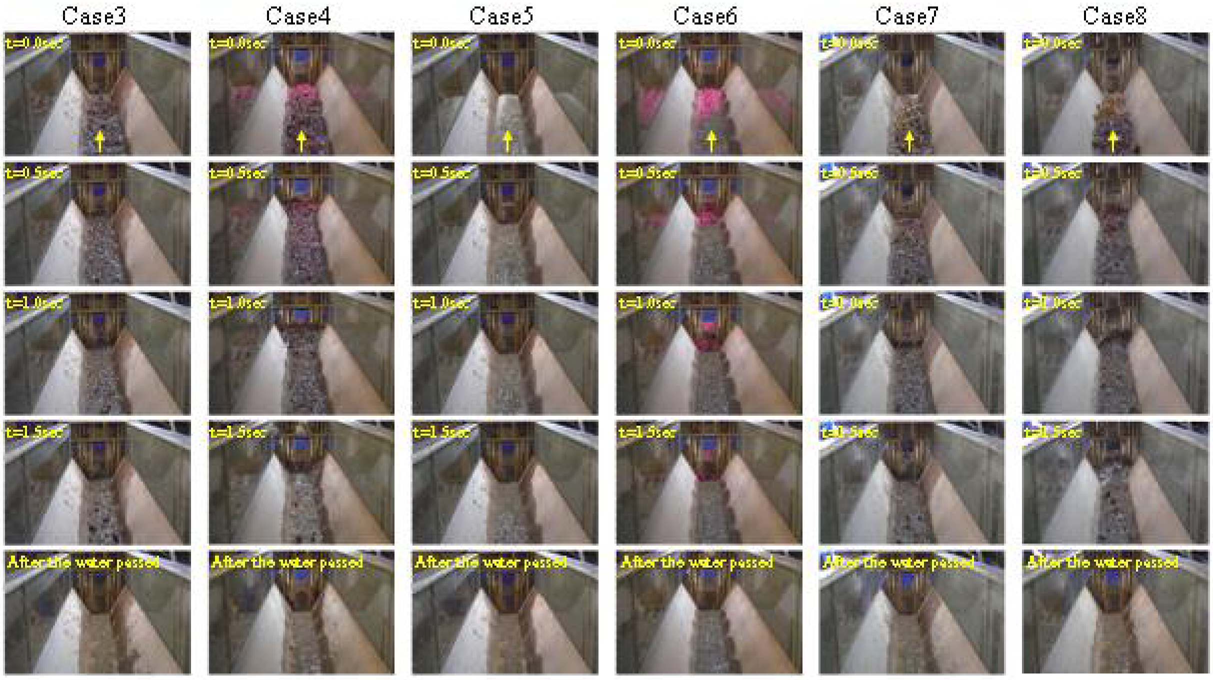

Photo 1 Images of the instant the debris flow passed the trees in experiments 3-8

time that goes by before the obstruction breaks appear to have a great influence. According to the conditions for occurrence or non-occurrence of dam up (Hasegawa, *et al.* 2003) for a Froude number of 1.87, the height required for dam up to occur is 25.7 cm. Therefore, if there is a temporary mountain-stream obstruction with a height of 10-13 cm, dam up will not occur.

Subsequently, the breakage of the obstruction progressed gradually, and after the water passed, almost all of the sediment in the temporary mountain-stream obstruction flowed downstream. In other cases (case3, 5, 6 & 7), even after the woody debris momentarily blocked the channel, sediment flowed past without accumulating, so there was no formation of a temporary mountain-stream obstruction. Later on as well, the flow conditions were the same as when there were no woody debris.

Figure 4 shows the discharge, and Figure 5 shows changes in concentration of debris flow over time. In all cases in which coarse sand was used (case1-4 & 7-9), a debris flow front was formed. The discharge was then Q_{out}/Q_{in}=3.4-3.9 (Q_{out} : outflow discharge at peak, Q_{in}: inflow discharge). Even in cases in which there was formation of a temporary mountain-stream obstruction (case4 & 8), there was no noticeable difference in outflow discharge at peak. The discharge ratios for case1 were 1.16 and 1.19. The values for subsequent flows (t=4.0 sec or more) were slightly higher: 1.21-1.42. The concentration of sediment declined sharply at the front end. Because the total volume of sediment outflow during the period of continual flooding was the same in every case, the sediment concentration in subsequent flows was slightly higher. This tendency is the same as that which occurs in the case of a slit-type sabo dam, even though it was only seen during a short period of time. In all cases in which $\mathbf{S_2}$ was used (case5 & 6), a debris flow front was not formed; a wedge-shaped mass of debris flowed downstream. Because the woody debris flowed close to the surface of the water, they flowed separately from the debris flow (Nakagawa, *et al.* 1994). Therefore, even if the woody debris got caught on trees, they hardly had any effect on the movement of the debris flow.

The length, number, and shape of the woody debris, as well as the narrow width part of the channel, all had a great influence on the formation of temporary mountain-stream obstructions. When the narrow width part of the channel (w) / length of woody debris (l)=1.67, there is formation of a channel obstruction that does not break in a short time. In the experiment

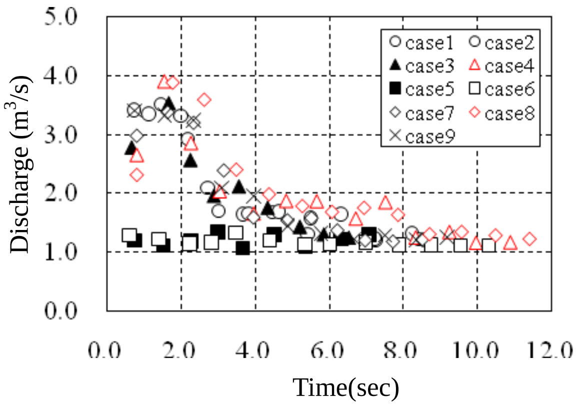

Fig.4 Temporal variation in discharge

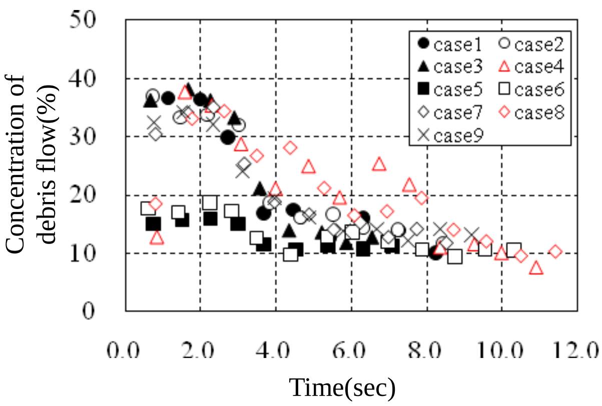

Fig.5 Temporal variation in concentration of debris flow

(Ishikawa, *et al.* 1989), in the case of $w/l \geqq 1.3$, hardly any woody debris became trapped. However, the experiment estimated the amount of woody debris to be 2% of the amount of sediment, according to the results of on-site observation, whereas in our experiment, it was about 5%, and about 60% if only the front part was considered. This is thought to account for the differences between the two experiments.

CONCLUSIONS

Sometimes a temporary mountain-stream obstruction forms in a debris flow that contains woody debris. Because differences in inflow discharge and time required for the obstruction to break do not cause flooding like the flooding that occurs on the sand-accumulation side of a large-scale landslide dam, we could not confirm that the discharge required for the breakage increased remarkably. Also, it is possible that in cases where there was a temporary mountain-stream obstruction, the discharge was overestimated when it was measured after the passage of water, because the water depth was high. When trees that acted as supports for the formation of a temporary mountain-stream obstruction, or the woody debris themselves broke, the discharge may have increased sharply. In the future, when there is a bank slope collapse, or an outflow of sediment from a tributary such as a zero-order torrent, it will be necessary to check what the right conditions are for the formation of a temporary mountain-stream obstruction.

EXPERIMENT 2 (INBESTIGATION OF WOODY DEBRIS TRAPPING)

Most conventional facilities for woody debris trapping are installed on the cross-section surface of a sabo dam, where the water flows past, and in accordance with the "Manual of Technical Standard for designing Sabo facilities against debris flow and woody debris" (The Ministry of Land, Infrastructure and Transport, *et al.* 2007) the interval is determined based on the maximum length of a woody debris, and the height of the levee crown of the countermeasure work is determined based on the water depth at dam up and the maximum diameter at chest height. However, if one looks at works for woody debris trapping on site, and at the woody debris that accumulate around bridge supports, the logs is sometimes piled several layers high. This could result in the water level rising further due to a narrowing of the part of woody debris trapping that allows water to pass through, and at the peak discharge, overflowing the levee crown of woody debris trapping, causing logs to flow downstream. Also, an accumulation of several layers of logs could cause a sudden decrease in the outflow of sediment, scouring of structures directly downstream, and riverbed degradation downstream. We conducted a hydraulic model experiment that reproduced actual topography, in order to consider ways of woody debris trapping from a new perspective. Here we introduce some examples of possible methods.

Topographical model

We made a 1/60 scale model of the Kajikamizu sabo dam located upstream from the Nishiyama Dam on the Hayakawa River, a right-branch tributary of the Fujikawa river system. The part we reproduced is shown in Figure 6 and Photo 2. We made the upstream edge of the model one of the ends of the sediment storage area, and the downstream edge the Kajikamizu sabo dam. For the first-stage riverbed, we used measurement data from fiscal year 2004. Watershed data is shown in Table 2.

Fig.6 Location of target rivers.

Experimental conditions

The flood-wave form used for our experiment was based on a hydrograph for a planned flood with a peak discharge of 2,400 m^3/s, set according to the rainfall of August 2, 1982, shown in Figure 7. A tiered waveform was used. Based on the results of a 2007 survey of riverbed materials, we decided to use mixed sand with grains measuring up to 500 mm in diameter and grains with an average diameter of 55 mm. Because the same volume flowed out of cross-section No. 10 (see Photo 2). regardless of the total amount of sediment flowing from the upstream edge of the model, the total amount of sediment was set at 510,000 m^3, an amount that can maintain a gradient of 2/3 (I=1/86), which is the planned accumulation gradient for a dam. The woody debris models were made of wooden cylinders, and the number of woody debris was determined according to the results of a 1996 survey. We used 160 logs measuring 5 m in length, 930 measuring 10 m, and 5,511 measuring 15 m — 6,601 logs (12,850 m^3) with a diameter of 42 cm in all. We chose two

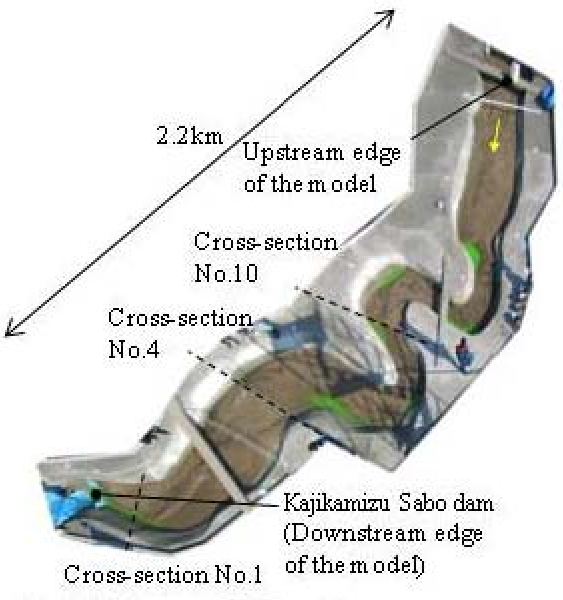

Photo 2 Topographical model

Table 2 Field dimensions of the Haya River.

Items	Dimensions
Catchment area	137km^2
Design discharge	2,400m^3/s
Average riverbed gradient	1/65
River width	100m

periods for putting in the logs: the two-hour peric of planned flood wave (Figure 7 (a) : case1) and the eight-hour period until a low water level of 1,200 m3/s (Figure 7 (b) : case2). The reason for this was that we wanted to verify differences in the woody debris trapping conditions when there is a high concentration of woody debris flowing downstream and when there is a low concentration of woody debris flowing downstream. We set the amount of woody debris for each discharge level by means of a flow ratio.

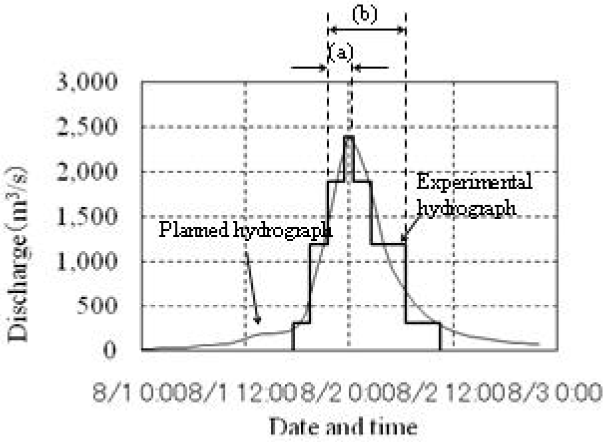

Fig.7 Planned hydrograph and experimental hydrograph

Photo 3 Woody debris flow at the peak discharge

Photo 4 Woody debris sometimes accumulate on a sand bar

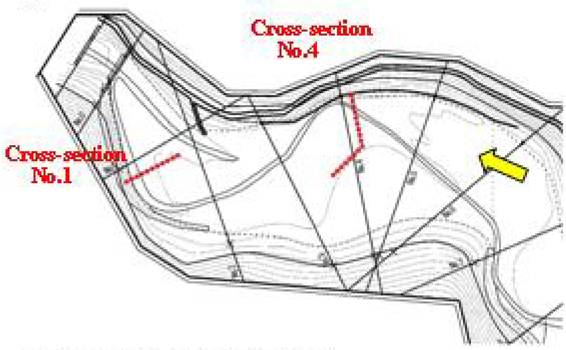

Fig.8 Woody debris trapping

Ideas for a woody debris trapping

We verified the current flow conditions of logs (without woody debris trapping). At the peak discharge, the flow widens to the whole width of the river channel, and the woody debris flow in the range shown in Photo 3. Moreover, an accumulation forms on the upstream left-bank side of cross-section No.1, and about 30% of the woody debris flow into this area and become temporarily trapped. However, in the low-water period, all of the woody debris flow out. In the central area of cross-section No. 4, woody debris sometimes accumulate on a sand bar, as shown in Photo 4. As a result, we came to the following conclusions, summarized in Figure 8: (1) when woody debris trapping works trap logs in the vicinity of the section impacted by the water, scouring of the leg portion happens easily, so as much as possible, woody debris should be trapped in the range where accumulations form on the left-bank side of cross-section No. 1, (2) the works should lead woody debris that flow down along the right bank to the range in which accumulations occur, (3) the fact that woody debris accumulate because of the formation of a gravel bar around cross-section No. 4 should be made use of. As for woody debris trapping works at cross-section No. 4, because the right-bank side is close to the water-impact section, after the woody debris are trapped, the force applied to the countermeasure works is greater. For this reason, countermeasure works are bent towards the downstream side to lessen the volume of logs trapped. However, because the overall volume of trapped logs cannot be reduced, we positioned the works in a way that made it easy for the woody debris to be led to the countermeasure works downstream. In accordance with the “Guidelines for the Design Technology for Countermeasures against Debris Flows and Floating Wood, and its Interpretation”, we made the interval in the woody debris trapping works the maximum woody debris length ×1/2 = 7.5 m (for countermeasure works with a diameter of 50 cm, the net interval was 7.0 m). We measured the water level and the height of the woody debris accumulation in our experiment to estimate the height with approximately 14 m on the downstream side and 10 m on the upstream side, according to the actual riverbed level. However, if one considers the deepest riverbed level at the peak discharge, a height of about 20 m is required on both sides. Even if a woody debris trapping is installed in the flow of Kajikamizu sabo dam, a height of 15 m is required.

Experiment results

Under present conditions, all of the woody debris flow out of the sabo dam at the downstream edge of the model, but woody debris trappings caught logs, as shown in Photo 5. About 81-97% of the woody debris that flow downstream are trapped, and the higher the density, the higher the ratio of logs that are trapped. Moreover, the volume of sediment that is trapped after woody debris are trapped increases by about 30,000 m^3 compared to present conditions. Figure 9 shows the deepest riverbed and maximum water depth cross-section directly downstream from the woody debris trapping on the downstream side, and Figure 10 shows a cross-section of the upstream side. On the downstream side, scouring of up to 2.8 m occurs from the initial riverbed height, and the water depth from the average initial riverbed height reaches a maximum of 10.9 meters. On the upstream side, , scouring of up to 8.0 m occurs from the initial riverbed height, and the water depth from the average initial riverbed height reaches a maximum of 6.3 meters.

Photo 5 Woody debris trappings caught logs

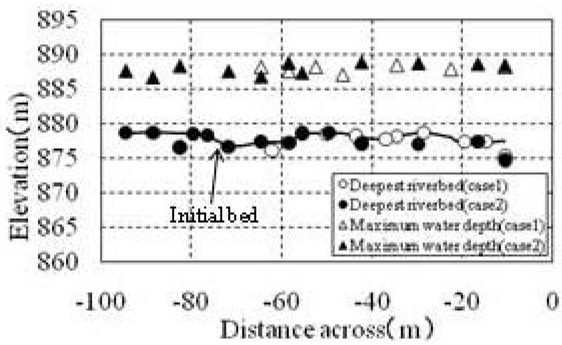

Fig.9 The deepest riverbed and maximum water depth from the woody debris trapping on the downstream side

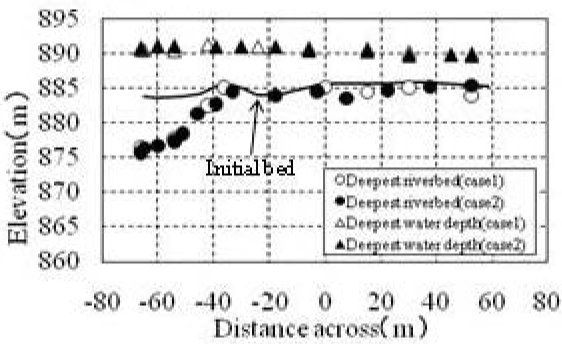

Fig.10 The deepest riverbed and maximum water depth from the woody debris trapping on the upstream side

Because the right-bank side of the woody debris trapping on the upstream side is the section struck by the water, there is significant scouring, and countermeasures such as bank protection by means of revetment or foot protection works, and countermeasures against leg scouring are required. Moreover, after carrying out the countermeasures, it will be necessary to measure the water at its deepest point again.

CONCLUSIONS

To investigate ways of woody debris trapping, we carried out an experiment from a new perspective, using a topographical model. After grasping the way in which woody debris flow down an actual river channel, we installed a woody debris trapping on the sedimentation site of a dam without intersecting the river channel, and showed that it was effective in trapping woody debris with relatively little blockage of sediment flow. We also demonstrated that in addition to conventional countermeasure works designed solely for the purpose of trapping woody debris, there is a need for countermeasure works designed to guide the woody debris to the area where they should be trapped. Moreover, there is a need to investigate changes in a river channel that occur when a woody debris trapping is installed on the sedimentation site of a dam. However, we verified the changes that occurred in this section from 1970 to 1995 by means of aerial photographs, and since we did not see any great change, we expect the above investigation to be fully effective .

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