A comparison of wood-sediment-water mixture flows at a closed type and an open type of check dams in mountain rivers

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ABSTRACT: The debris flow event in Hofu City, Yamaguchi Prefecture, Japan on July 21, 2009 yielded a large amount of sediment transport and woody debris in the mountain river basin, where a closed type of check dam and an open type of check dam were built (Maricar et al., 2011). Based on laboratory tests, the debris flow control by these check dam was studied. This paper compares the deposition process of sediment grains and pieces of wood at the open and closed check dam in a laboratory flume experiment. The experimental results showed that the open check dam trapped the wood pieces and the trapped pieces deposited the sediment grains behind themselves. On the other hand, the closed check dam made most of wood pieces pass through the check dam and most of sediment grains get trapped in the water pool behind the closed check dam.

1 INTRODUCTION

In mountain river basins, such as those in Japan, debris flows instantaneously transport large quantities of sediment and pose a hazard to human life and infrastructure. Many researchers have been investigating countermeasures against debris flow event. In particular, the control of debris flows by check dams has been examined by laboratory and field studies (Armanini & Larcher, 2001; Bovolin & Mizuno, 2000; Busnelli et al., 2001; Maricar et al., 2011; Mizuyama et al., 1995; Mizuyama et al., 2000; Osti et al., 2007; Wu and Chang, 2003).

Closed and open types of check dams have been installed in order to capture debris flows in the mountain areas. However, the closed type always has to be kept empty to trap a large amount of sediment during a debris flow event. On the other hand, the open type allows finer sediment to pass through at lower discharge and coarser sediment to be trapped at higher discharge such as debris flow. From these characteristics of each type of check dams, the open type becomes more popular than the closed type. However, designing an appropriate opening becomes a difficult subject (e.g. Ashida and Takahashi, 1980; Ashida et al., 1987; Armanini, 2001).

Although check dams have been installed in the mountain torrents, these system may not always help to control debris flow of an anticipated discharge. Because they might have previously been filled up with sediment transported by a number of smaller flood events and debris flows in the torrent (Lien, 2003; Mizuyama et al., 2000; Osti and Egashira, 2008; Shrestha et al., 2007). Therefore, it becomes important for check dams to have a potential storage volume for an inflowing sediment volume (Mizuno et al., 1996; Mizuno et al., 2000).

The debris flow event in Hofu City Yamaguchi Prefecture, Japan on July 21, 2009 yielded a large amount of sediment and driftwood in the Tsurugi and Hachimandani River, where a closed type of check dam and an open type of check dam was built (Maricar et al., 2011).

The closed check dam did not trap driftwood but sediment from the debris flows (Figure 1). This resulted in the significant outflow of wood from the

Figure 1. Sediment deposition caused by the closed check dam in the Tsurugi River.

Figure 2. Sediment and driftwood trapped by the open check dam (beam type) in the Hachimandani River.

Tsurugi river basin. On the other hand, the open check dams trapped a large amount of driftwood in their opening and as a result a large amount of sediment (Figure 2). This interrupted the outflow of wood and sediment from the Hachimandani River basin. This paper compares the deposition processes of sediment and driftwood in the open and closed check dam with laboratory flume experiments.

2 EXPERIMENTAL METHOD

2.1 *Model check dam and laboratory flume*

The experiments were carried out to compare the deposition processes of sediment and driftwood at the open check dam and the closed check dam (Maricar et al., 2011; Maricar et al., 2012). The open check dam was built in a rectangular flume; it was 12 m long, 30 cm wide, and 32.8 cm high with smooth glass walls. A schematic diagram of this flume is shown in Figure 3. The flume bed was composed of movable and fixed parts; the movable part was 6 m long and the fixed part is 4 m long. The fixed bed was roughened with the same material used for the movable bed. The bed sediment grains and wood were placed on the movable bed part and the check dam model was on the fixed part of the bed.

Referring to the steel-pipe check dam in the Hachimandani River, we made the model of the open check dam for the laboratory experiments. Figure 4 (a) shows the situation of the check dam in the Hachimandani River, and Figure 4 (b) shows the check dam in the laboratory flume. Stainless steel tubes with a diameter of 18 mm were used for the model of the open check dam. The reduced size of the prototype was 1/50. The opening size of this check dam model was l_0=3.5 cm. The check dam was set 1.5 m from the downstream end.

Referring to the closed check dam in the Tsurugi River, we made the model of the closed check dam for the laboratory experiments. The model was made with impermeable plywood, as shown in Figure 5. The reduced size of the prototype was 1/120. It is schematically shown in Figure 6.

2.2 *Bed material and model wood*

The grain classes with a diameter d_{50} = 3.6 mm, 7.4 mm and 22mm were mixed to produce the movable bed material. The mixing ratio of the gravel, fine gravel and very coarse sand was 1: 2.5: 5. The representative diameter of the mixture was d_{50} = 4.4 mm. The grain density was 2.65 g/cm^3. The particle size distribution of the mixture is shown in Figure 7, and the sediment and wood conditions are shown in Table 1. The largest size of the sediment grains almost correspond to the opening size of the model check dam (l_0=3.5 cm).

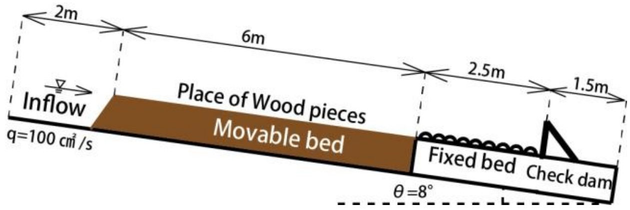


Figure 3. Laboratory flume

Figure 4(a). The open check dam in the Hachimandani River.

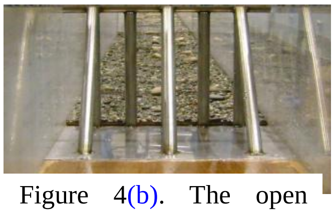
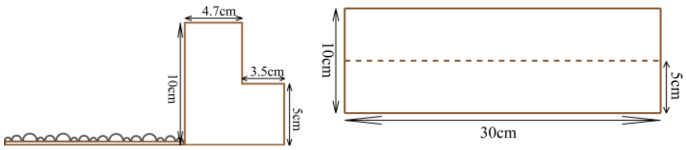


Figure 4(b). The open check dam in the laboratory flume.

Figure 5. Closed check dam in the flume (view from the right-hand and downstream side).



(a) side view (b) front view

Figure 6. Scale of the closed check dam in the flume.

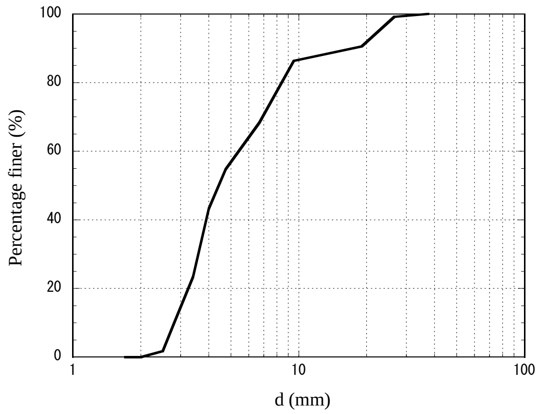


Figure 7. Particle size distribution curve for the mixture in the experiment.

Table 1. Characteristics of model sediment and wood.

Material	Grain density (g/cm3)	Wood density (g/cm3)	Diameter (mm)	Length (cm)
Bed sediment grain	2.65		d_{50}=4.4	
Wood A		0.76	2	10
Wood B		0.68	3	10
Wood C		0.66	4.1	10
Wood D		0.65	5.2	10

Model wood was made of cylindrical Japanese cypress. Four kinds of wooden cylinder were used as shown in Table 1. Their length was set equal to 10 cm.

Prior to a test, the pieces of wood were soaked in water and then placed with different orientations on the movable bed surface. The wood density was 0.65~ 0.76 g/cm^3. Number density of the wood was 1 piece/(10cm*10cm). Figure 8 shows the initial situation of wood pieces on the movable bed. The sediment bed of 10 cm depth was filled with water.

Mixture flow of sediment, wood and water was triggered by the quick inflow of water from the upstream end and moved downstream along the flume bed. Most of the wood pieces accumulated at the flow front and then arrived first at the check dam. Sediment followed the wood pieces accumulating at the flow front. The experimental conditions are shown in Table 2. Eight experimental runs were conducted under different number densities. For comparison, the experimental run without wood was also made under the same hydraulic condition. The duration of the water inflow from the upstream end was around 20 seconds.

The movement and deposition processes of sediment grains and wood pieces were analyzed from images shot by the video cameras. After stopping the water inflow, the number of wood pieces and the amount of sediment stopping and passing the check dam were measured. The sediment bed elevation behind the check dam was also measured with the point gauge.

Figure 8. Initial situation of wood pieces on the movable bed in the flume.

Table 2. Experimental condition.

No.	Type	q_{wo}	q_g	L_t	θ_0	Diameter of each wood piece	Piece length	Number of each wood piece	Number of all the piecess	l_0/L
		(cm^2/s)	(cm^2/s)	(m)	(°)	D_i (mm)	L (cm)	N_i	N	
1	Open type	101	-	3	8°	2, 3, 4.1, 5.2	10	22 (D_i=3, 4.1) 23 (D_i=2, 5.2)	90	0.35
2	Open type	104	9	4	8°	2, 3, 4.1, 5.2	10	30	120	0.35
3	Open type	101	5	2	8°	2, 3, 4.1, 5.2	10	15	60	0.35
4	Open type	100	6	6	8°	2, 3, 4.1, 5.2	10	45	180	0.35
5	Open type	102	8	4	8°	2, 3, 4.1, 5.2	10	30	120	0.35
6	Open type	101	8	2	8°	2, 3, 4.1, 5.2	10	15	60	0.35
7	Open type	104	8	0	8°			0	0	
8	Closed type	100	8	4	8°	2, 3, 4.1, 5.2	10	30	120	0

3 EXPERIMENTAL RESULTS AND DISCUSSION

3.1 *Field survey*

In the Tsurugi River, wood did not accumulate but sediment deposited at the closed-check dam. This resulted in the significant outflow of wood and sediment from the Tsurugi river basin.

In the Hachimandani River, on the other hand, wood accumulated in the opening of the open-check dams so that the accumulation completely interrupted the sediment transport to the downstream direction.

3.2 *Behavior of wood-sediment-water mixture at the open check dam*

The experiments show that some of the wood concentrating at the flow front were trapped by the open check dam. The trapped pieces formed a kind of the mesh structure at the open check dam and led to sediment deposition behind the trapped pieces from the subsequent flow (Figure 9).

A linear relationship can be found between the volume of wood trapped by the check dam and the volume of all the pieces on the fixed bed. However, trapping the pieces by the open-check dam model requires a sufficient number and volume.

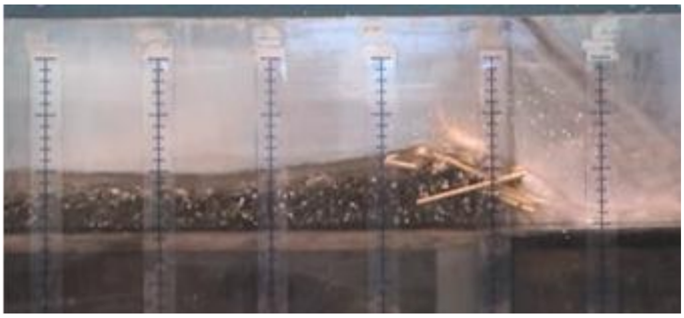


Figure 9. Flow situation 10 seconds after the arrival of the flow front at the open check dam.

3.3 *Behavior of wood-sediment-water mixture at the closed-check dam*

The flow situation before and after the arrival of the flow front at the check dam is shown in Figure 10 and 11. Water and wood were concentrated at the flow front and sediment followed. A pool of water produced immediately after the flow front arrived at the check dam. Sediment was deposited at the head of the pool and wood floated towards the check dam. In around 4 seconds after the arrival of flow front at the check dam, the complete wood pieces passed through the check dam. At the same time, the pool caused sediment deposition in the upstream direction of the subsequent flow (Figure 12). This result suggests that closed check dams interrupt sediment transport completely but cause significant downstream transport of wood.

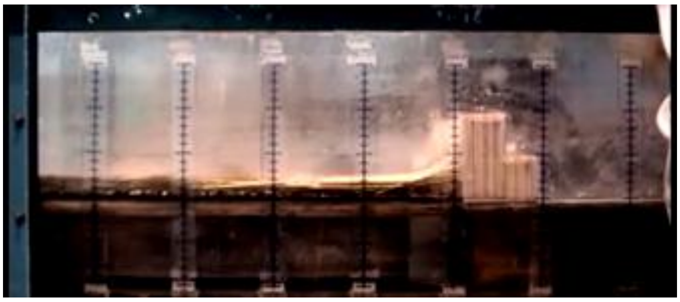


Figure 10. Flow situation at arrival time of the flow front at the check dam model.

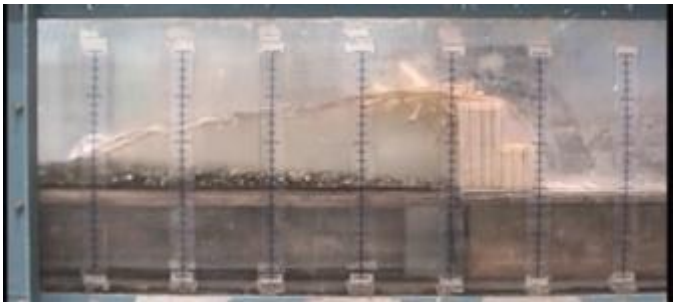


Figure 11. Flow situation 2.4 seconds after the arrival of the flow front at the closed check dam.

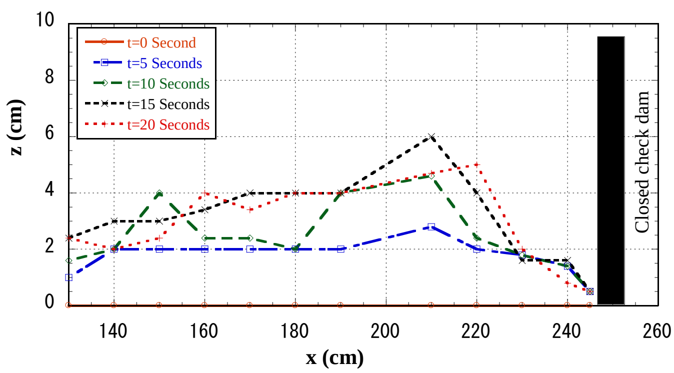


Figure 12. Sediment deposition process (L_t=4m, closed check dam).

3.4 *A comparison of the closed-check dam and the open-check dam behavior*

Figure 13 shows the ratio of wood pieces stopping at the check dam to all the wood pieces moving on the fixed bed. It is found that about 60% of all the pieces were trapped by the open check dam and about 40% passed through the open check dam. In the case of the closed type, 100% passed through the check dam.

Figure 14 shows the weight ratio of the sediment trapped at the check dam. The weight ratio of sediment grains trapped at the open check dam to the overall mass was around 70 %. In the case without wood pieces, however, most of sediment passed through the open check dam. In the case of the closed type, most of the sediment remained at the closed check dam. If the flow contains sufficient wood, 60~70% of the mixture was trapped by the open check dam. On the other hand, the closed type trapped most of the sediment and most of wood passed through the check dam.

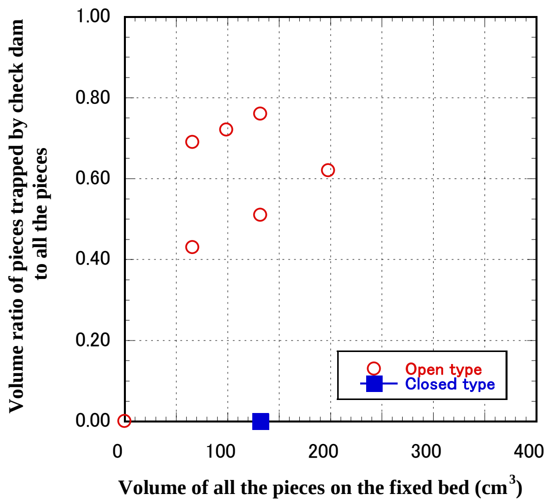


Figure 13. Volume ratio of wood pieces trapped by check dam model to all the pieces moving on the fixed bed.

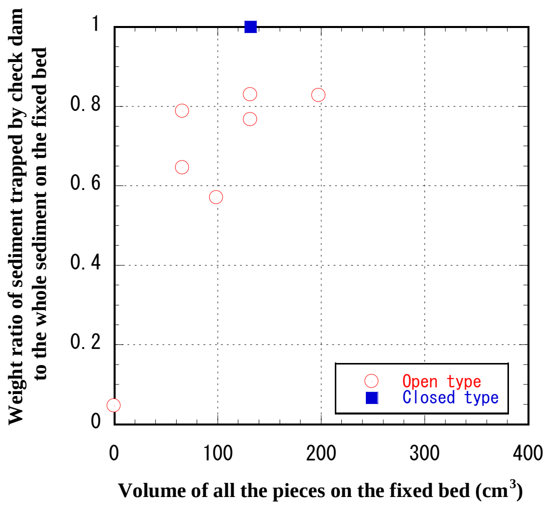


Figure 14. Weight ratio of sediment deposited in relation to the overall mass.

The trap efficiency of open check dam depends on the wood concentration. The wood concentration is determined by vegetation on steep slopes and river banks causing landslide and erosion. Therefore, it is assumed that the trap efficiency of the open check dam accompanies uncertainties.

Figures 15 and 16 show the final longitudinal profiles of the sediment deposition behind the open and closed type of check dams, respectively. Plan views of the sediment deposition are shown in Figures 17 and 18. Three dimensional bed forms appeared in the case of open check dam and two-dimensional bed forms are produced in the case of the closed check dam.

These figures indicate that the open check dam caused sediment deposition behind the trapped wood

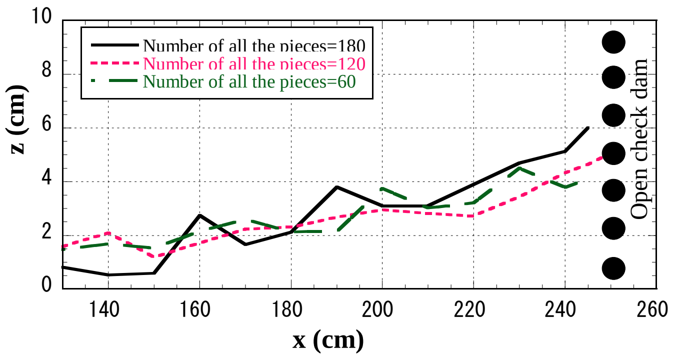


Figure 15. Longitudinal profile of sediment deposition behind the open type of check dam.

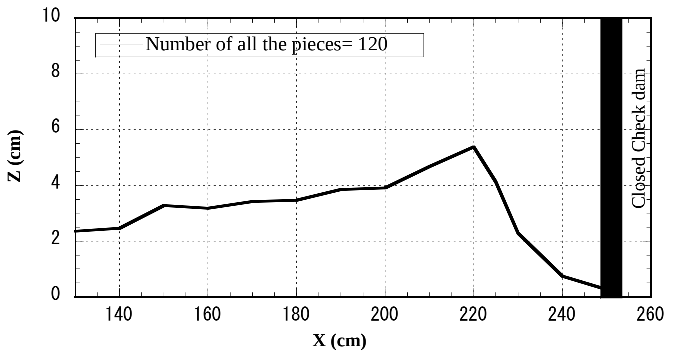


Figure 16. Longitudinal profile of sediment deposition behind the closed type of check dam.

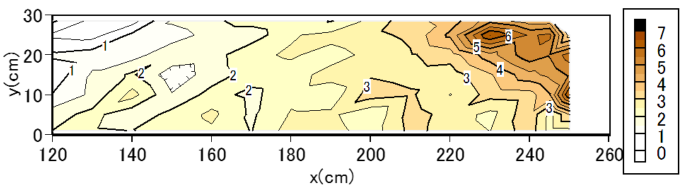


Figure 17. Contour plot of the bed configuration of the sediment deposition behind the open check dam.

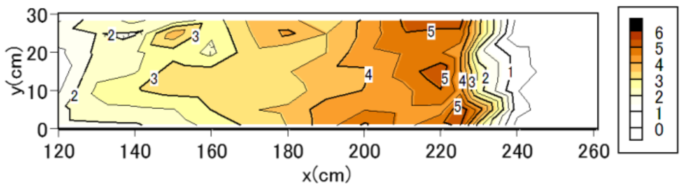


Figure 18. Contour plot of the bed configuration of the sediment deposition behind the closed check dam.

pieces. On the other hand, the closed check dam produced sediment deposition at the inlet of the water pool and gradually made it move in the upstream direction.

4 CONCLUSIONS

The results obtained in the laboratory experiments on a comparison between closed type and open type of check dams are summarized as follows:

1. The closed check dam made most of the wood pass through the check dam and most of the sediment grains get trapped in the water pool behind the closed check dam. Therefore, closed check dams can reduce the sediment transport but may cause wood pieces transport downstream.
2. The open check dam trapped 60~70% of the mixture, if the mixture contains sufficient wood. The trap efficiency of open check dams depends on the vegetation on the adjacent slopes and riverbanks causing landslides and erosion. Therefore, it is found that the trap efficiency of the open check dam accompanies uncertainties.
3. Three dimensional bed forms (locally irregular pattern) appeared in the case of open check dam and two-dimensional bed forms are produced in the case of closed check dam.

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