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EFFECT OF TWO SUCCESSION CHECK DAMS ON DEBRIS FLOW DEPOSITION

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6 ABSTRACT

This paper describes the effect of two successive check dams on the debris flow event which occurred on 21 July, 2009 in Hofu City, Yamaguchi Prefecture, Japan. The debris flow event caused sediment deposition in the check dams in the Tsurugi and Hachimandani River. In the former river with two successive closed-check dams, driftwood did not accumulate in the check dams but in the central region of the river bend. In the latter river with two successive open-check dams, driftwood accumulated in the opening of the check dams so that the accumulation obstructed the sediment transport to the downstream direction. The upstream check dams in these rivers have sediment deposition profile of around 2°, whereas the downstream ones have deposition profile of around 1.3°. The ratio of sediment deposition volume in the downstream check dams to that in the upstream ones is 0.3 : 1. The total amount of sediments trapped by the two successive check dams can be estimated at around 9,500 m³ in each river. Specific sediment runoff volume from the mountainous areas is $q_s = 6,800$ (m³/km²).

KEY WORDS: two successive check dams, debris flow, sediment deposition, closed-check dam, open-check dam

INTRODUCTION

The control of debris flows by check dams has been investigated by experimental and numerical studies and field surveys (ARMANINI & LARCHER, 2001;

BOVOLIN & MIZUNO, 2000; BUSNELLI, STELLING & LARCHER, 2001; MIZUYAMA, KOBASHI & MIZUNO, 1995; MIZUYAMA, ODA, NISHIKAWA, MORITA & KASAI, 2000; OSTI, ITOH & EGASHIRA, 2007; WU & CHANG, 2003). It is generally believed that check dams can reduce sediment transport to downstream river reaches and stabilize river beds. Check dams must act to lower the peak sediment discharge and to decrease the total volume of sediment outflow to the downstream area.

There are two-types of check dams; one is a closed type and the other is an open type. The former type is a traditional structural measure for controlling debris flow. However, this type of check dams has to be empty in order to trap large amounts of sediment during a debris flow event. The latter type can be subdivided into slit-check dams and beam-check dams. Concrete slit-check dam is known as the slit type, and steel-pipe open dam is known as the beam type. An open type allows finer sediments to pass through at lower discharge and coarser sediments to be trapped at higher discharge such as debris flow. However designing their appropriate opening becomes a problem.

The Hofu City in Yamaguchi Prefecture, Japan had heavy rain on July 21, 2009. The accumulated rainfall was 240.5mm and the largest hourly rainfall was 63.5mm/hour. This rainfall caused many shallow landslides on the mountainous areas of this city. Most of these landslides changed into debris flows and moved downstream in the mountainous rivers.

There are two-types of check dams in these rivers; one is a concrete closed-check dam and the other is a steel-pipe open-check dam. Especially, the two successive closed-check dams were installed at the Tsurugi River and the two successive open-check dams were installed at Hachimandani River before this debris flow event. After the debris flow event, significant sediment deposition was observed in these check dams.

In order to consider the measures against debris flows in the mountainous areas, it is necessary to know the effect of check dams against the debris flow event. This requires an investigation into the effect of the check dams on the sediment deposition from debris flows.

The purpose of the present study is to estimate the effect of the check dams against debris flows from the comparison of river bed profiles before and after the debris flow event.

6 STUDY AREA

The study area is located in Hofu City, Yamaguchi Prefecture, Japan (Fig. 1). Geology of its mountain region is mainly composed of fresh and weathered granite. As a result, this region is vulnerable to landslides and debris flows. The government of Yamaguchi Prefecture has made effort to prevent landslides and debris flows. Therefore, 23 check dams have been installed to control river bed erosion and bed sediment runoff in the mountain region of Hofu City. There are two-types of check dams in these rivers, i.e. a closed type and an open type.

The Tsurugi River and the Hachimandani River are selected as the study areas. In the Tsurugi River,

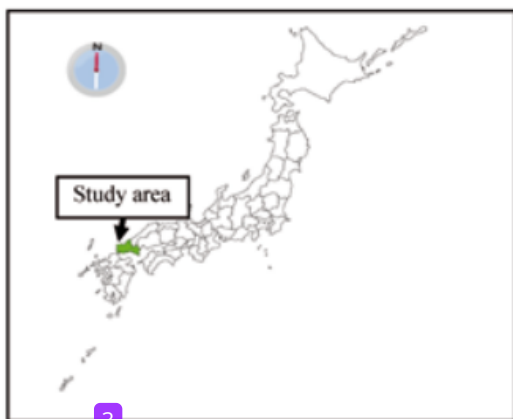


Fig. 1 - Location of the study area

two successive closed-check dams have been constructed at a distance of about 200 m, while in the Hachimandani River two successive open-check dams have been constructed at a distance of about 400 m.

OUTLINE OF THE DEBRIS FLOW DISASTER

Hofu City area had heavy rainfall on July 21, 2009. The situation of the rainfall is shown in Figure 2. This figure also shows the time-varying water level of the small river in Hofu City. The accumulated rainfall was 240.5mm from 4 a.m. to 1 p.m. The hourly rainfall had two times of peak of 65 mm from 8 to 9 a.m and 49.5 mm from 11 to 12 a.m. This rainfall caused flood flows in every river in Hofu City area. The flood water level of the small rivers had also two times of peak, as shown in Figure 2.

This rainfall condition resulted in many shallow landslides in the mountain region. Most of the landslides changed into debris flows and then moved down the mountain rivers. In their downstream areas, there are villages, a nursing home for elderly people, and roads. In Yamaguchi Prefecture the impact of the debris flows resulted in 17 deaths, 33 houses destroyed, 95 houses partially damaged, 708 houses inundated upstairs and 3,862 houses buried of sediments (Fig.3). Some of the witness of this event shows that most of the debris flows occurred at around 12 a.m. Therefore, we can consider that the second peak of the hourly rainfall triggered most of the landslides. The landslide sediments moved into the second peak flood flows. These transported a significant amount of sediment to the downstream river reaches.

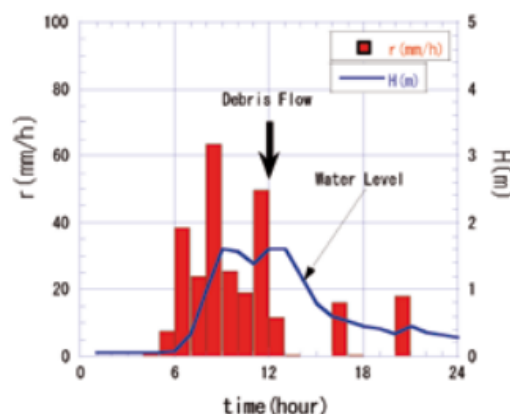


Fig. 2 - Rainfall at the Hofu station & water level of the Mate River in the downtown of Hofu City



Fig. 3 - Saba River basin



Fig. 4 - Catchment of the Tsurugi River

DEBRIS FLOW DEPOSITION BY CHECK DAMS IN THE TSURUGI RIVER

Figure 4 depicts the plan view of the Tsurugi River catchment. Figure 5 shows the longitudinal profile of the river. The distance from the upstream end (Position B) to the downstream end (Position A) is 2,700 m and its catchment area is about 2 km². River slope is 3.5° at position A in the vicinity of the national road and 14.2° at position B in the vicinity of the landslide location. On the other hand, river slope is 2.7° in the vicinity of the two successive check dams. An aerial photo shows that there are about 90 shallow landslides in this catchment area.

On November 25 to 27, 2009 and on December 7 to 8, 2009, we visited the Tsurugi River and then found that a significant amount of sediment was trapped in the check dams. We surveyed the sediment deposition areas of check dams. We also took sediment samples from the river bed. Sediment grain size analysis was carried out by sieve method at the Hydro Laboratory.

THE UPSTREAM CHECK DAM IN THE TSURUGI RIVER

Figure 6 is a photo of the situation of sediment deposition caused by the upstream check dam in the Tsurugi River. The sediment deposition formed new river bed configuration behind the check dam after the debris flow event. Figure 7 shows

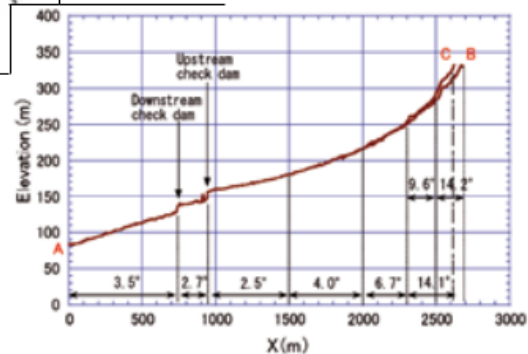


Fig. 5 - Longitudinal profile of the Tsurugi River



Fig. 6 - Sediment deposition caused by the upstream check dam on the Tsurugi River (View from upstream to downstream direction on November 27, 2009)

the contour map of the river bed elevation. This river reach has a curvature and an inflow of another debris flow from the left-hand side. It can be seen that the river bed has higher part in the outer region and lower part in the inner region of the river bend. Driftwood did not arrive at the check dam but stopped in the central region of the river at $x=50$ m. Here x is defined as distance measured along the centre line in the upstream direction from the check dam.

Figure 8 illustrates the cross-sectional profile of

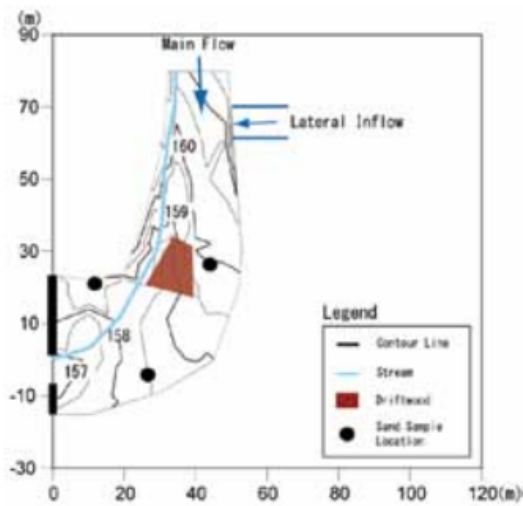


Fig. 7 - Contour map of river bed configuration behind the upstream check dam in the Tsurugi River

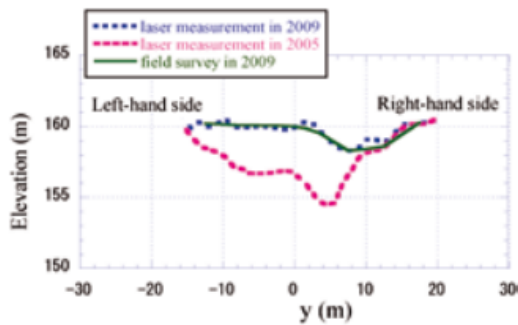


Fig. 8 - Cross section of the river bed profile in the upstream check dam ($x=50\text{ m}$)

the river bed at $x=50\text{m}$. The solid line in this figure denotes the field measurements after the debris flow event. For comparison, the laser measurements before and after the debris flow event are also shown by the dashed lines in this figure. The laser measurements were made by the Ministry of Land, Infrastructure, Transport and Tourism on April 14 to 16, 2005 and on August 17 to 19, 2009. It is confirmed that the field measurement coincides with the laser measurement. The right-hand side within the river bed after the event has depression at around $x=50\text{ m}$. The formation of this depression represents serious sediment deposition in the outer region (left-hand side) and less sediment deposition in the inner region (right-hand side) of the river bend during the event. From such a figure of the field measurements we obtain the maximum and minimum elevation of the river bed at each section.

Using the maximum and minimum bed elevation

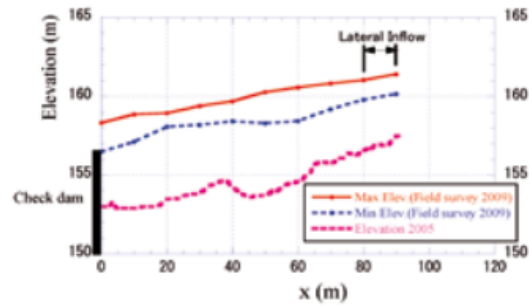


Fig. 9 - Longitudinal profile at the upstream check dam in the Tsurugi River

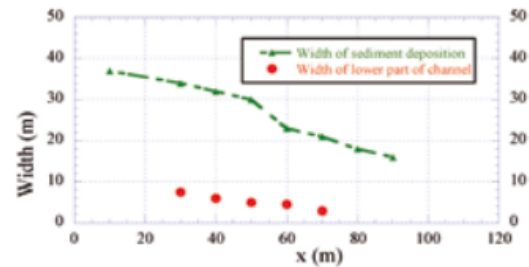


Fig. 10 - Width of sediment deposition and the lower part of channel in the storage region of the upstream check dam

at each section yields a longitudinal river bed profile behind the check dam, as shown in figure 9. In this figure, we omitted the laser measurement in 2009, because the field measurement approximated to the laser measurement after the debris flow event.

The longitudinal river bed slope after the debris-flow event can be estimated as 1.9° from the field measurement in 2009, while the slope of the river bed before the event is 3.3° from the laser measurement in 2005.

In addition, Figure 10 shows a change in width of sediment deposition zone with distance x from the check dam. The width of the sediment deposition zone changes with distance ranging from 37 m to 16 m, whereas the width of the lower part of the river bed ranges from 7.5 m to 3 m and its depth from 1.5 m to 2 m. Using the measurements of river bed before and after the debris flow event, we can estimate the volume of deposited sediment as $7,400\text{ m}^3$

THE DOWNSTREAM CHECK DAM IN THE TSURUGI RIVER

Figure 11 is a photo of sediment deposition at the downstream check dam in the Tsurugi River. Figure 12 shows the contour map of the river bed elevation behind the check dam. There is a lateral inflow upstream immediately from the check dam. The other



Fig. 11 - Sediment deposition caused by the downstream check dam on the Tsurugi River (View from downstream to upstream direction on December 8, 2009)

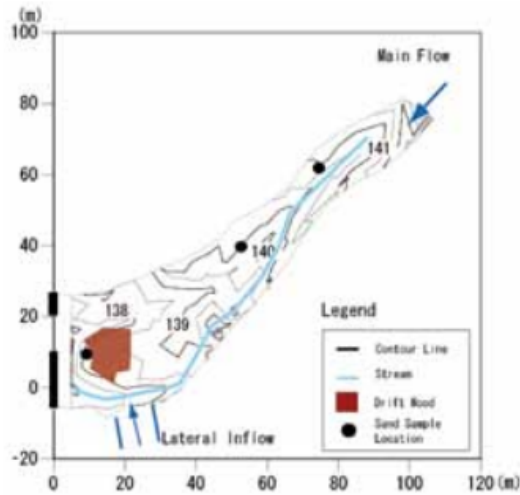


Fig. 12 - Contour map of river bed configuration behind the downstream check dam in the Tsurugi River

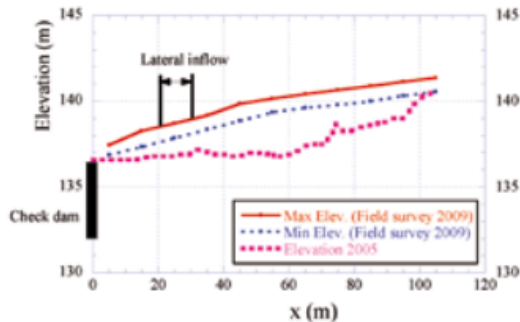


Fig. 13 - Longitudinal profiles at the downstream check dam in the Tsurugi River

debris flow moved into the main river from the left-hand side. This inflow resulted in significant sediment deposition and driftwood accumulation.

Using the maximum and minimum bed elevation at each cross section yields a longitudinal river bed profile behind the check dam, as shown in figure 13. This longitudinal profile becomes convex upward. The bed slope is steeper in the region such that $0 < x < 50$ m than in the other region. This is attributed to the lateral inflow of the other debris flow. However, no effect of

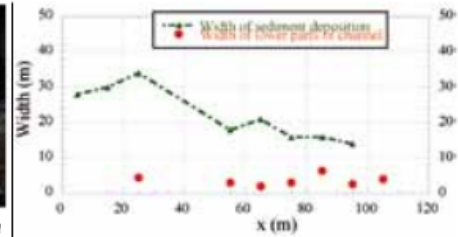


Fig. 14 - Width of sediment deposition and the lower part of channel in the storage region of the downstream check dam

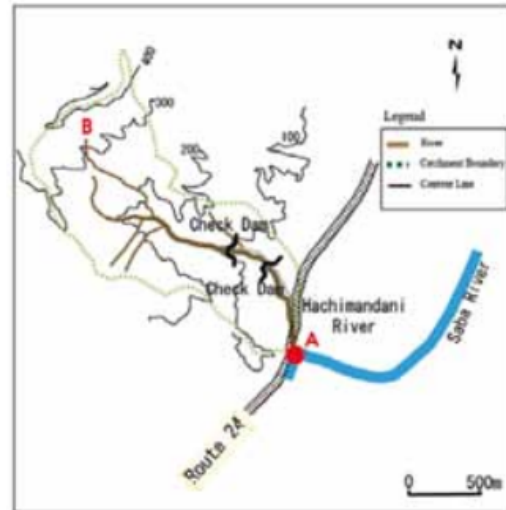


Fig. 15 - Catchment of the Hachimandani River

the lateral inflow can be seen in the river region at $x > 50$ m. The longitudinal slope of the sediment deposition profile is 3.4° in the region with the effect of lateral inflow. The longitudinal slope of the sediment deposition profile is 1.4° in the region without the effect of lateral inflow, while the slope of river bed based on the laser measurements in 2005 indicates 4.5° . This approximated to the river bed slope before the debris flow event.

Figure 14 shows the change in width of sediment deposition zone with distance x from the check dam. The width of sediment deposition zone decreases from 34 m to 14 m. On the other hand, the width of the lower part of the bed decreases from 6.4 m to 2 m and its depth is 1.0 m. The volume of sediment trapped in the check dam can be estimated as $2,200 \text{ m}^3$.

DEBRIS FLOW DEPOSITION BY THE CHECK DAMS IN THE HACHIMANDANI RIVER

Figure 15 depicts the plan view of the Hachimandani River catchment. Figure 16 shows the longitudinal profile of the river. The distance from the upstream

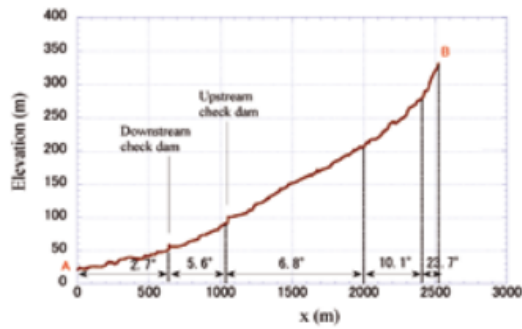


Fig. 16 - Longitudinal profile of the Hachimandani River



Fig. 17 - Sediment deposition caused by the upstream check dam on the Hachimandani River (View from downstream to upstream direction on December 8, 2009)

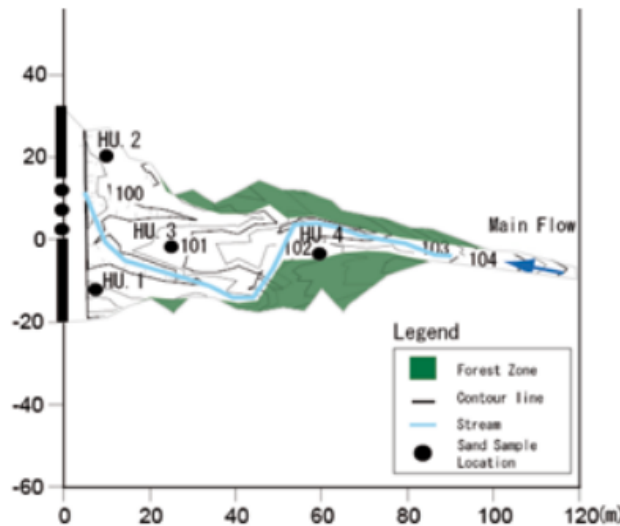


Fig. 18 - Contour map of river bed configuration behind the upstream check dam in the Hachimandani River

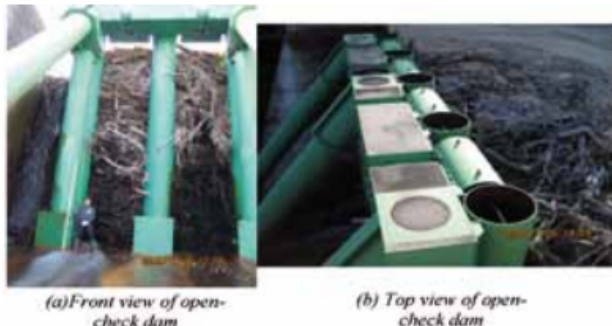


Fig. 19 - Sediment and driftwood at the upstream check dam in the Hachimandani River

end (Position B) to the downstream end (Position A) is 2,500 m, and the catchment area is about 1.7 km². River slope is 2.7° at the confluence with the Saba River (position A) and 23.7° at position B in the vicinity of the landslide location. On the other hand, the river slope is 5.6° in the vicinity of the two successive check dams. An aerial photo shows that there are about 10 shallow landslides in this catchment area.

On November 25 to 27, 2009 and on December 7 to 8, 2009, we visited the Hachimandani River and then found that a significant amount of sediment was trapped in the check dams. We measured river bed elevation in the sediment deposition areas of the check dams. We also took sediment samples from the river bed. Sediment grain size analysis was carried out by sieve method at the Hydro Laboratory.

THE UPSTREAM CHECK DAM IN THE HACHIMANDANI RIVER

Figure 17 is a photo of situation of sediment deposition caused by the upstream check dam on the Hachimandani River. Figure 18 shows the contour map of the river bed configuration behind the check dam. Figure 19 are the photos of the open-type check dam. We found that driftwood had accumulated in the opening of the check dam. However we did not find larger size of sediment such as boulders in the opening of the check dam or in the sediment deposition area. The accumulation of driftwood obstructed the sediment transport in the downstream direction. Figure 20 shows grain size distribution of deposited sediment behind the check dam. We find the 50% diameter $d_{50} = 1.38 \text{ mm}$ on the average. Since there are no boulders in the sediment deposition area, $d_{50} = 1.38 \text{ mm}$ is typical of the deposited sediment.

Using the maximum and minimum bed elevation at each cross section yields a longitudinal river bed profile behind the check dam, as shown in figure 21. Figure 22 shows the change in width of sediment deposition zone with distance x from the check dam. The longitudinal slope of sediment deposition zone before and after the debris flow event is 6.3° and 2.0°, respectively. The width of the sediment deposition zone varies

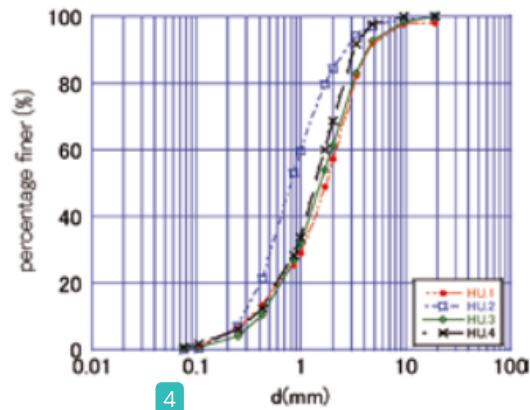


Fig. 20 - Grain size distribution of sediment at the upstream check dam in the Hachimandani River

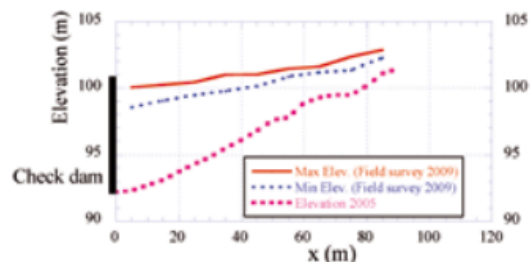


Fig. 21 - Longitudinal profiles at the upstream check dam in the Hachimandani River

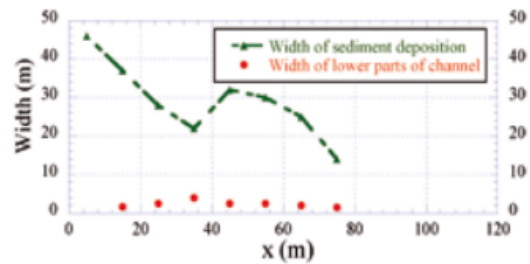


Fig. 22 - Width of sediment deposition and the lower part of channel in the storage region of the upstream check dam



Fig. 23 - Sediment deposition caused by the downstream check dam on the Hachimandani River (View from upstream to downstream direction on November 25, 2009)

from 14 m to 46 m. The width of lower part of the river bed is from 1.5 m to 4 m and its depth is from 0.5 m to 1.5 m. The volume of the trapped sediment can be estimated as 7,300 m³.



Fig. 24 - Sediment and driftwood at the downstream check dam in the Hachimandani River on November 25, 2009

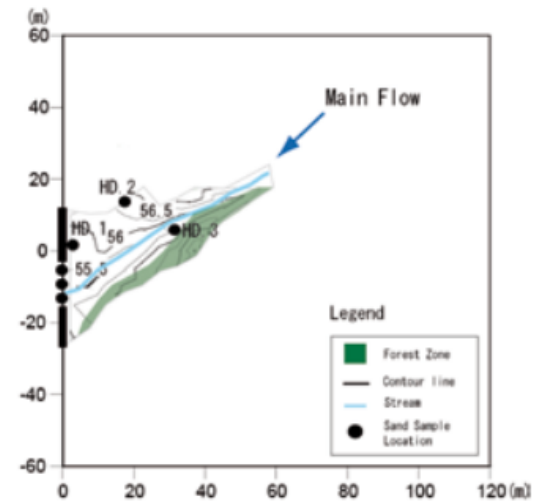


Fig. 25 - Contour map of river bed configuration behind the downstream check dam in the Hachimandani River

THE DOWNSTREAM CHECK DAM IN THE HACHIMANDANI RIVER

Figure 23 is the photo of sediment deposition caused by the downstream check dam on the Hachimandani River. Figure 24 show the photos of the open-type check dam. Figure 25 shows the contour map of the river bed configuration behind the check dam. We found the driftwood accumulated in the slit part of the check dam. However we did not find larger size of sediment such as boulders in the opening of check dam or in the sediment deposition area. The accumulation of the driftwood obstructed the sediment transport to the downstream direction. Figure 26 shows grain size distribution of deposited sediment behind the check dam. We find the 50% diameter $d_{50} = 0.99 \text{ mm}$ on the average. Since there are no boulders in the sediment deposition area, $d_{50} = 0.99 \text{ mm}$ is typical of deposited sediment.

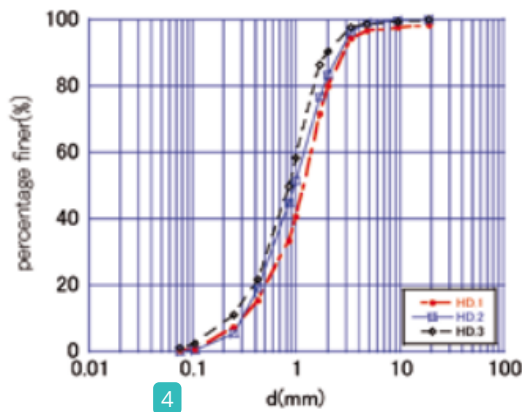


Fig. 26 - Grain size distribution of sediment at downstream check dam in the Hachimandani River

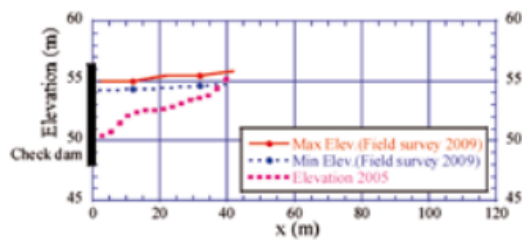


Fig. 27 - Longitudinal profile at the downstream check dam in the Hachimandani River

Using the maximum and minimum bed elevation at each cross section yields a longitudinal river bed profile behind the check dam, as shown in figure 27. Figure 28 shows the change in width of sediment deposition zone. The longitudinal slope of sediment deposition zone before and after the debris flow event is 7.1° and 1.3° , respectively. The width of the sediment deposition zone varies from 19m to 35m. The width of lower part of the river bed is from 2m to 4m and its depth is from 0.5m to 1.0m. Using the results, we can estimate the volume of the trapped sediment as $2,200 \text{ m}^3$.

DISCUSSION

Characteristics of the sediment deposition in four check dams are summarized in Table 1.

The curvature of river course produced space-variation in river bed at the upstream check dam in the Tsurugi River. The lateral inflow of the other debris flows caused an increase in bed elevation due to significant deposition at the check dam areas in the Tsurugi River. The vegetation zone flattened river bed elevation in the Hachimandani River. The Hachimandani River has less space-variation in river bed than the Tsurugi River, because the Hachimandani River has no curvature and lateral inflow near the check dams.

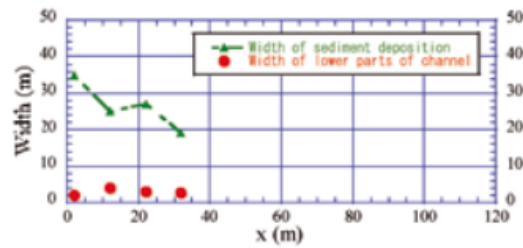


Fig. 28 - Width of sediment deposition and the lower part of channel in the storage region of the downstream check dam

Although the Tsurugi and Hachimandani River differ significantly in their river bed slope before the debris flow event, sediment deposition profiles after the event have their almost same longitudinal slope in the upstream and downstream check dam, respectively.

The upstream check dam areas have deposition slope of around 2° , and the downstream ones have deposition slope of around 1.3° . The upstream check dam areas have steeper longitudinal profiles of sediment deposition than the downstream ones.

The downstream check dam area reveals more convex profile than the upstream one in the Tsurugi River.

Driftwood accumulated above the river bed surface near the region of river bend and lateral inflow in the Tsurugi River, whereas it accumulated in the opening of the open-check dams in the Hachimandani River. The accumulation of driftwood in the opening of the check dams obstructed the transport of the whole sizes of sediment to the downstream direction.

Grain size analysis of the sediment samples shows $d_{50} \approx 1.4 \text{ mm}$ for the upstream check dams and $d_{50} \approx 1.0 \text{ mm}$ for the downstream check dams. However, boulders could not be found in the sediment deposition areas of check dams of the Hachimandani River but could be found in those of the Tsurugi River.

The volume of sediment trapped by the upstream check dam in the Tsurugi River is almost same as that by the upstream check dam in the Hachimandani River. The volume of sediment trapped by the downstream check dam in the Tsurugi River is same as that by the downstream check dam in the Hachimandani River. The ratio of sediment volume by the downstream check dams to that by the upstream ones is 0.3:1. The total amount of sediments trapped by the two successive check dams is about $9,500 \text{ m}^3$ in each river. This result reduced the sediment outflow from the mountainous areas to the residential areas. It is concluded that more severe disasters have been avoided by the two successive check dams.

	Tsurugi River		Hachimandani River	
	Upstream check dam	Downstream check dam	Upstream check dam	Downstream check dam
Longitudinal river bed slope before the event	3.3°	4.5°	6.3°	7.1°
Longitudinal river bed slope after the event	1.9°	3.4° (0.5 ≤ x ≤ 50m) 1.4° (50m ≤ x)	2.0°	1.3°
River bed configuration after the event	Sediment deposition at the outer side and bed erosion at inner side in the river bend region	Sediment deposition near the lateral inflow	Sediment deposition in the central part of the river bed	Nearly flat
Lower part of the river bed	Width = 3~7.5m Depth = 1.5~2m	Width = 2~6.4m Depth = 1m	Width = 1.5~4m Depth = 0.5~1.5m	Width = 2~4m Depth = 0.5~1m
Driftwood accumulation position	In the central region of the river bend area	Near the lateral inflow	In the opening of the check dam	In the opening of the check dam
Boulder	Boulders near the lateral inflow	Boulders near the lateral inflow	No boulders	No boulders
d_{50}	1.42mm	0.96mm	1.38mm	0.99mm
Width of River behind the check dam	16~37m	14~34m	14~46m	19~35m
Volume of the trapped sediment	7,400m ³	2,200m ³	7,300m ³	2,200m ³

Tab. 1 - Summary of the investigation into the check dams in the Tsurugi and Hachimandani River

For the discussion we introduce the concept of specific sediment runoff volume q_s per one debris flow event (ASHIDA *et alii*, 1983):

$q_s = (\text{total amount of sediment outflow from river basin by one debris flow event}) / (\text{river basin area})$

Here m³ and km² are used as unit for the amount of sediment outflow and the area of river basin, respectively.

Total amount of sediment outflow by the debris flow event in the Tsurugi and Hachimandani River basin can be approximated by the volume of sediment trapped by the two successive check dams. These river basin areas have same value of 1.4 km² at the downstream check dams. Therefore, we can obtain the same specific sediment runoff volume $q_s = 6,800$ (m³/km²) for the Tsurugi and Hachimandani River. This specific sediment runoff volume is slightly smaller than the other events (ASHIDA *et alii*, 1983).

CONCLUSION

The results obtained in this study are as follows:

1. In the Hachimandani River, driftwood accumulated in the opening of the open-check dams so that the accumulation obstructed the sediment transport to the downstream direction. In the Tsurugi River, on the other hand, driftwood did not accumulate at the closed-check dam but in the central region of the river bend.

2. Although the Tsurugi and Hachimandani River differ significantly in the river bed slope before the debris flow event, sediment deposition profiles after the event have their almost same longitudinal slope in the upstream and downstream check dam, respectively. The upstream check dam areas have deposition slope of around 2°, whereas the downstream ones have deposition slope of around 1.3°.

3. Grain size analysis of sediment from the sediment deposition areas of the upstream check dams shows $d_{50} \approx 1.4$ mm, while that of the downstream check dams shows $d_{50} \approx 1.0$ mm. However, boulders could not be found in the sediment deposition areas of check dams of Hachimandani River but could be found in those of the Tsurugi River.

4. The volume of sediment trapped by the upstream check dams in the Tsurugi and Hachimandani River is about 7,300 m³. The volume of sediment trapped by the downstream check dams in the Tsurugi and Hachimandani River is 2,200 m³. The ratio of sediment volume by the downstream check dams to that by the upstream ones is 0.3 : 1. The total amount of sediments trapped by the two successive check dams is about 9,500 m³ in each river. These result in the same specific sediment runoff volume $q_s = 6,800$ (m³/km²) for the Tsurugi and Hachimandani River.

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