Landslide Dam Outburst Flood in Way Ela River, Ambon Island, Indonesia

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Landslide dam outburst flood brings tremendous hazards. In order to mitigate damages, adequate information on a landslide dam outburst flood is necessary such as sediment transport and changes of features before and after the dam break. However, it is still not enough. In 2012, a large-scale landslide dam was formed in Ambon Island, Indonesia. One year later, an outburst flood occurred and washed away a downstream village in July, 2013. Authors carried out field reconnaissance survey, topographical analysis and grain size analysis before and after the outburst flood. Topographic changes are clarified and hydraulic properties are also discussed. The trend of topographic changes accords with that indicated in previous cases of the 2008 Iwate-Miyagi Nairiku earthquake. The longitudinal profile of particle size seems to relate to the threshold of particle size of incipient motion. Based on the planar change of the particle size, we estimate the flood process on the alluvial fan.

Key words: landslide dam, outburst flood, longitudinal profile, grain size distribution

1. INTRODUCTION

Landslide dam outburst floods have brought tremendous hazards in the past all over the world [*Costa and Shuster*, 1988; *Tabata et al., 2002*]. In order to mitigate those damages, potential hazard area due to debris flows subsequent to landslide dam failures should be estimated promptly after the formation of a dam. For this purpose, numerical simulation has been developed and applied to actual hazard situations so far [*Satofuka et al., 2007; Ishizuka and Osanai, 2012*].

In order to acquire more accurate simulation results, it is important to accumulate data, which is relating to the shape of landslide dam before and after dam failure, the particle size distribution of a landslide dam and riverbed in downstream, the condition of the deposition and erosion due to sediment transport and concentration of deposited soil. Those data provide valuable information on setting parameters, verifying simulation results and improving simulation model. Based on a past landslide dam induced disaster, data relating topographic change, condition of damage in downstream area due have ever been reported and accumulated. [*Uchida et al., 2009; Yoshino et al., 2010*] However, reports relating to the breakdown of large scale landslide dams are limited.

In July, 2012, a large-scale landslide occurred and the collapsed soil mass formed a huge landslide dam along the Way Ela River in Ambon Island, Maluku province, the Republic of Indonesia. One year later, on 25th July, 2013, the flood subsequent to the dam failure hit the village, which was located in downstream of the landslide dam. After the

landslide dam was formed, the government of Indonesia started to construct channel works on the top of the landslide dam and organized the evacuation system for outburst flood hazard. As a result, only three people died or were missing out of 5,300 villagers.

Authors have conducted field reconnaissance survey several times to clarify the condition of the landslide dam before and after the outburst flood. Based on survey results and topographical data, we analyze the changes of topography and condition of the deposition and erosion.

Fig.1 Location of Way Ela River

2. BRIEF DESCRIPTION OF THE LANDSLIDE DAM OUTBURST FLOOD

2.1 Outline of the landslide dam

Ambon Island is located at latitude 3 dgrees south and longtitude 130 degrees east, about 2,500km from Jakarta toward east-northeast (**Fig.1**). On 13th July, 2012, a slope on the right-side bank of the river failed and formed the large-scale landslide dam three kilometers upstream from the sea. One kilometer upstream from the sea along the river is classified into alluvial fan. A village with the population of 5,300 is located on the alluvial fan (**Fig.2**). Outline of the landslide dam is summarized as shown **Table 1**. These figures are calculated based on satellite DEM data and ground survey data is also applied.

Ambon Island is mainly composed of granite and Quaternary volcanic rock, and the watershed of Way Ela River consists of pyroclastic deposit such as tuff breccia according to the geological map. Rainfall data before the landslide are not available, because there is no rain gauge located in neighborhood. In regards to the cause of the landslide, the earthquake of M5.6 in the near sea reportedly occurred on a day before landslide. However, the cause of the landslide is unknown.

The landslide is a large scale of about 500 m in width and about 100 m in depth. As the geological factor for the landslide, aggravation of weathering in deep layer, existence of fault along a scarp and less permeable bedrock could be considered.

Fig.2 Overview of the landslide dam

Table 1 Outline of the landslide dam

Landslide mass	Length in longitution		1,660 m
	Width	Max	320 m
		Min	140 m
	Relative height		137 m
	Landslide mass volume		17,000,000 m^3
	Elevation of the top		194.5 m
Dammed lake	Length in longitution		1,920 m
	Width	Max	460 m
		Min	40 m
	Depth		79.5 m
	Water volume		24,800,000 m^3
Watershed			13.43 km^2

2.2 Landslide dam outburst flood

Rainy season in Ambon Island is from May to August. From the beginning of rainy season in 2013, water level was gradually going up and it accelerated from the end of June. The heavy rainfall on 24th July raised the water level. It reached the top of the landslide dam and the water flow began through the still-under-construction drainage channel in the early morning on 25th July (①, ② in **Fig.3**). Erosion of downstream slope of the dam continued and it reached to the top of the dam. Then structures on the dam started to be broken due to the erosion around 12:00 (③, ④).

Rapid erosion started soon after the structures were broken down, and then huge scale outburst flood emerged around 12:30 pm (⑤). It continued until around 2:00 pm (⑥) and then surge flow disappeared. Flood spreads over the alluvial fan and two third of houses and buildings in the village were washed away by the flood (Fig.4).

Fig.3 Chronology of the outburst flood

3. METHOD

3.1 Field survey and topographical analysis

During the period between September in 2012 when the landsilde dam is formed and September in 2013 after the dam break, field reconnaissance survey to clarify the changes has been done. In the survey, we carried out preliminal topographical mesurement using hand-held laser range finder (Range Accuracy; 0.3m, Max Range; 1,000m), mesurement of flood marks on the river bank and alluvial fan, sampling of deposited sediment and collecting data in various kinds of aspects.

Table 2 Satellite images for DEM

	Satellite	Date
Before flood	WorldView-1 WorldView-2 QuickBird	8th Oct. 2012 – 10th Feb. 2013
After flood	WorldView-1 WorldView-2	7th Sept. 2013 – 7th Oct. 2013

In addition to the field survey, DEM data (mesh size 2m) using satellite images before and after the outburst flood were also formulated (**Table 2)**.

The elevation of the riverbed and the longitudinal profile of the riverbed gradient before and after the dam failure were calculated by using DEM data. Moreover, the elevation of the original riverbed before the formation of the landslide dam was calculated by using the topographic map at 1:50,000 scales.

3.2 Grain size analysis

In order to know longitudinal and planar variation of the particle size distribution of the sediment transported by the flood, grain size analysis was conducted at seven sites (one site before and six sites after the dam failure; **Fig.5**). The collection sites of sediment materials were decided after in-situ observation of the deposit condition. The site (A) is located in the riverbed section and site (B) is located on the right side of alluvial fan. It was recognized that the features of sediment material on site (A) and (B) were similar to that of the surrounding area respectively. For the left side bank of the alluvial fan, four survey sites were set because variety of grain seize distribution was observed.

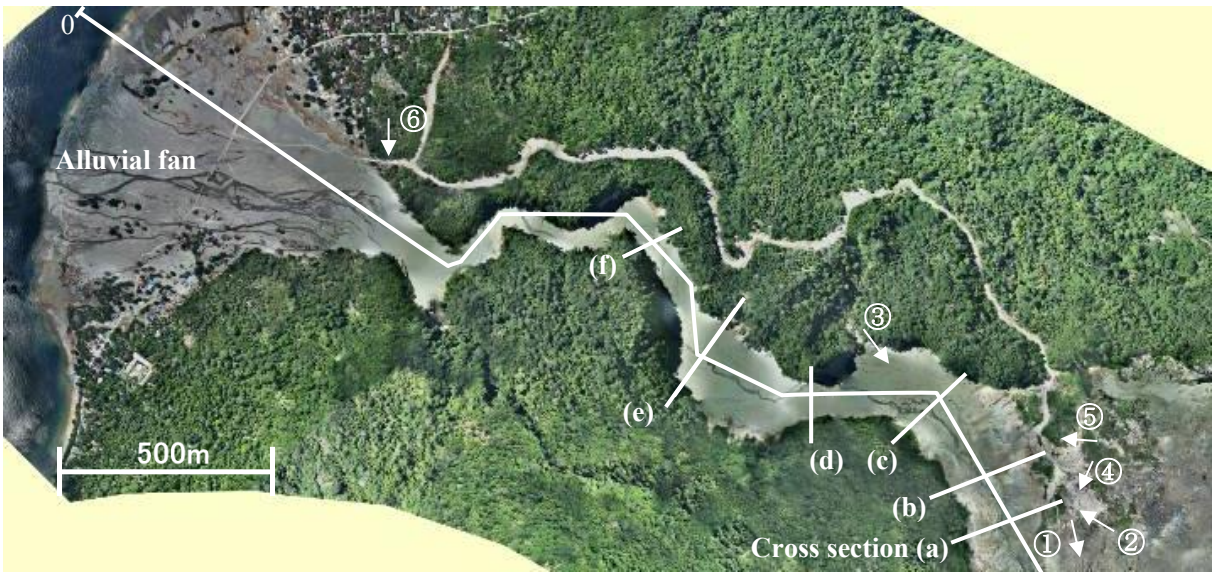

Fig.4 Way Ela River after the flood
(①-⑥show the location and direction of the photos in Fig. 3)

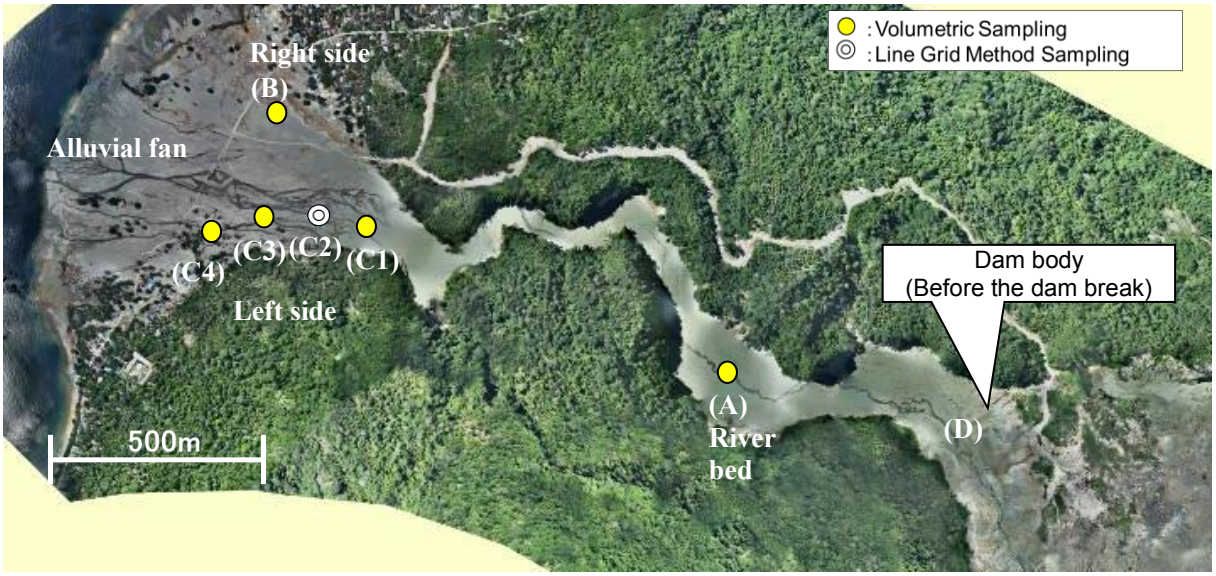

Fig.5 Location of the sampling points for grain size analysis

Volumetric sampling method was used to collect sediment materials. We selected a 50 cm long, 50 cm wide quadrilateral on each site and collected materials existed in 10 cm deep within the quadrilateral. If the particle size was larger than or equal to 75 mm, we measured the shortest, longest and middle diameter and the weight of each particle instead. On the other hand, if the particle size was smaller than 75 mm, we conducted sieve analysis.

On the left side of upper part of the alluvial fan (C2), there are many sizes of gravels which are larger than a fist. It was difficult to apply the volumetric sampling method. Hence, we applied the line grid method to the sediment around this site. The grid size of the method was 2 m. The gravel existed on 100 nodes (25 nodes in longitudinal line × 4 nodes in lateral line) was collected and the shortest, longest and middle diameter were also measured. The particle size was obtained by averaging these three diameters. Finally, we obtained the grain size accumulation curves. These sampling and measurement were done on 12th and 13th September 2013.

4. RESULTS AND DISCUSSION

4.1 Topographical changes

After the failure of the dam, the water level is approximately 65 m below the previous highest water level (**Fig.6**). The water flows over the present top of the dam. Part of the downstream slope of the remained dam is covered with big boulders and erosion of the dam body is not observed. Photos of 6 sections of the landslide dam and the downstream river is shown as **Fig.7**. The location of each sections is shown in **Fig. 4**.

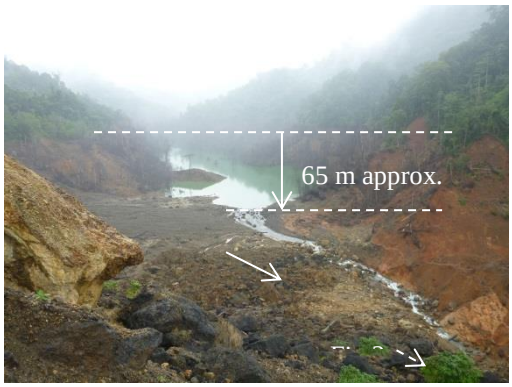

Fig.6 Remained landslide dam after the outburst flood

Section (a) and (b) are near the previous highest point on the landslide dam. Very steep water channel is formed after the overtopping and erosion. The width of the upper part of the water channel is approximately 250 m and the depth of erosion is about 70-90 m in this section. The slope gradient is about 30 degree for the right-side bank and about 50 degree for the left-side bank.

Section (c) is 300 m upper from the previous downstream end of the landslide dam; section (d). Both sides of the section (d) are upstanding rock wall and the width of the channel becomes narrowed. The deposit of sediment in this section after the dam break is about 30 m deep according to the diffierence between the two periods of DEM data before and after dam failure.

Similaly, the depth of the deposit in the section (e) and (f) is about 25-35 m. The width of the river channel in the section (e) is about 160 m and it is wider than upper part and down part of this section. The river channel width in the section (f) is about 70 m and the flood marks is 30 m higher than the

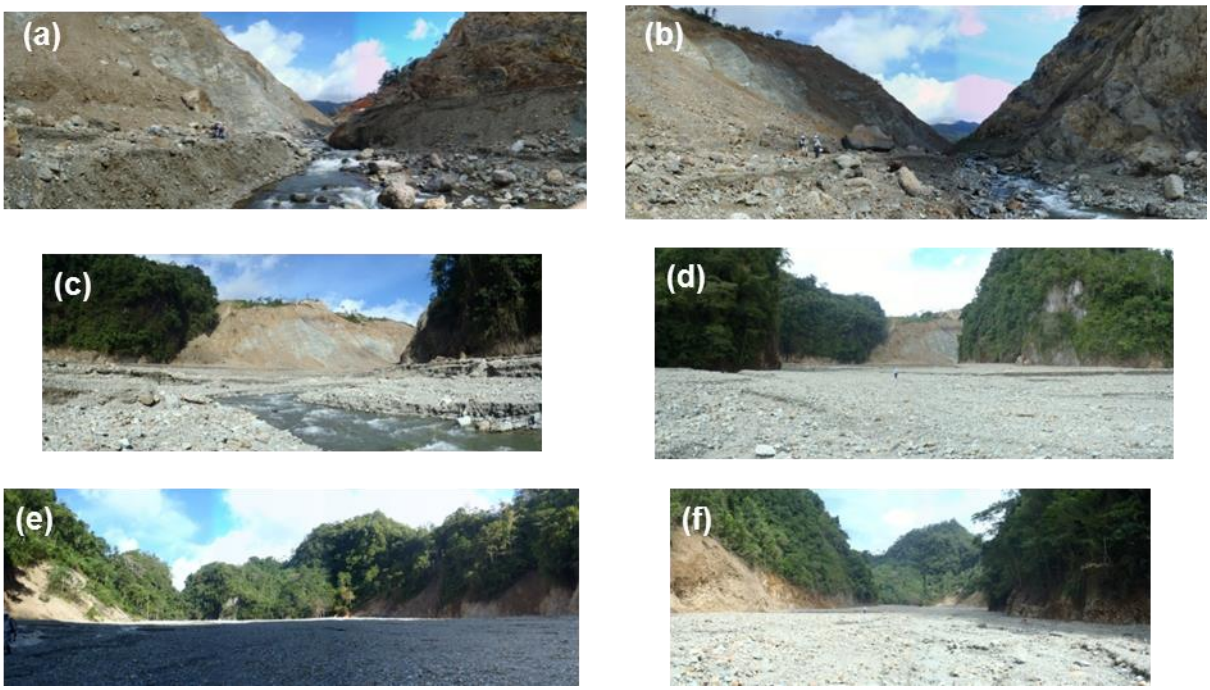

Fig.7 Photos of the landslide dam and the downstream river (View from downstream)

present riverbed for the right bank and 10 m heigher for the left bank. The down part from this section, the flood traveled down in relatively narrow and winding stream channel (**Fig.4**).

4.2 Longitudinal profile

The longitudinal profile and riverbed gradient are shown as **Fig.8**. The erosion due to the landslide dam outburst flood occurred, but the original riverbed is not eroded shown as **Fig.8** (a). It is noted that the sediment deposited in the area 1km downstream of the landslide dam (**Fig.7** (c)). The slope gradient is 0.9 degree at each point of the alluvial fan before and after the dam failure. The slope gradient in the landslide dam section changed from 6.8 – 19.1 degree to 2.8 degree . The channel located in the upper part of the alluvial fan was formed by curved and narrow part, so the sediment cannot flow smoothly and the sediment deposition progressed. Hence, the slope gradient of this section changes from 1.1 degree to 2.0 – 3.5 degree and becomes steeper than the value before the dam failure.

Yoshino et al. [2010] described the topographical

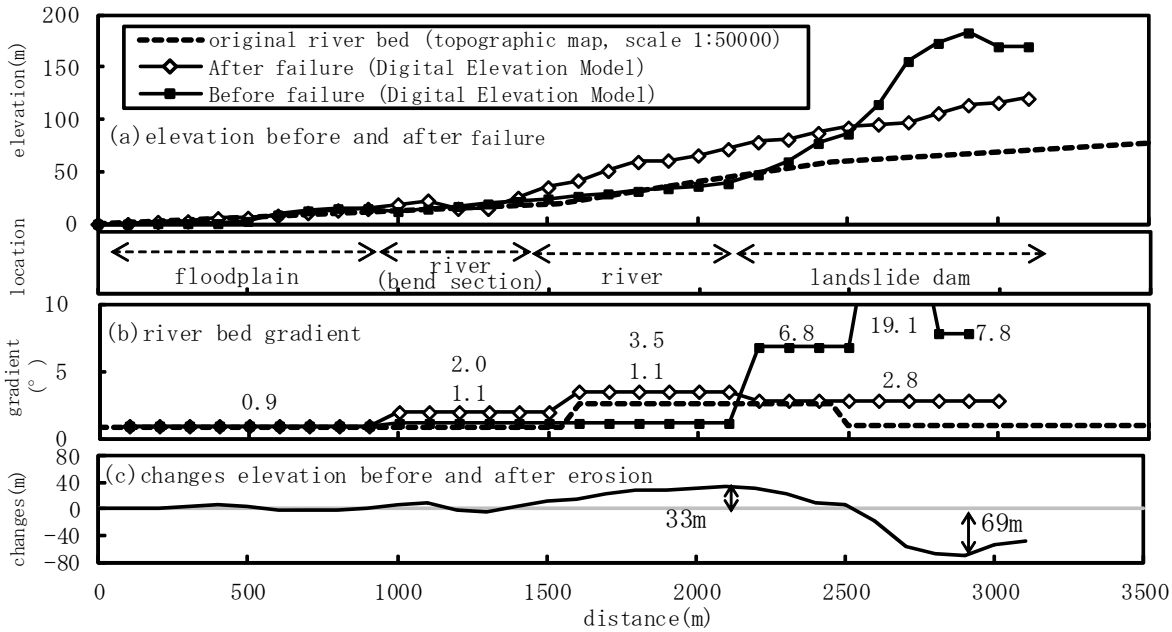

Fig.8 Changes of longitudinal profile and riverbed gradient

changes between before and after the dam failure in case of the landslide dams induced by the 2008 Iwate-Miyagi Nairiku earthquake as follows. The riverbed significantly degraded after the dam failure, but it is still higher than previous riverbed around the area where significant riverbed degradation occurred with dam break. In the aspect of the volume of landslide dam, the cases of Iwate-Miyagi Nairiku earthquake and Ambon Island is quite different. However, the tendency of topographical changes between before and after the dam failure is similar in both cases.

4.3 Grain size analysis

According to the previous reports and examination results, large gravels tend to deposit around the forefront of the debris lobes in an alluvial fan or edges of a deposited area [*Takahashi, 1980*]. In this study, the particle size distribution at the site on the left side of the lower part of the alluvial fan (C4), and on the right side of the alluvial fan (B) indicates that size of the sediment is smaller than the other site. The particle size distribution at the site on the middle part of the left side of the alluvial fan (C2) indicates that larger size of the sediment exists (**Fig.9**).

Using the height of flood marks, topographic data, Manning formula and Iwagaki's formula, we calculated the threshold of particle size of incipient motion at the site C1 where the river channel curves and at the site C2 where boulders deposited. In the calculation of Manning formula, the value of 0.05 was used for coefficient of roughness (n). **Fig.10** shows the threshold of particle size of incipient motion at C1 and C2. According to the figure, the threshold of particle size of incipient motion at C2 is smaller than the value at C1 and also than the value of d_{50} obtained at C2; 88 cm. Hence, it is estimated that the forefront of the debris flow containing boulders stopped and the sediment deposited at C2. The river channel in upper stream of the apex of the alluvial fan is curved rightward. It could be considered that debris flow with boulders traveled down along the excurvation and reached around the leftward area including C2. Given the fact that smaller particles deposited around the site B and C4, the subsequent flow containing smaller particles after the forefront of the debris flow travelled down bypassing or overtopping the deposited boulders around the site C2.

Around the site B, a vertical hole had been excavated about 1 m depth above the original ground line. Alternate deposition of gravels and sands was observed there. This suggests that the debris flow might oscillate horizontally or a number of surge flows might occur.

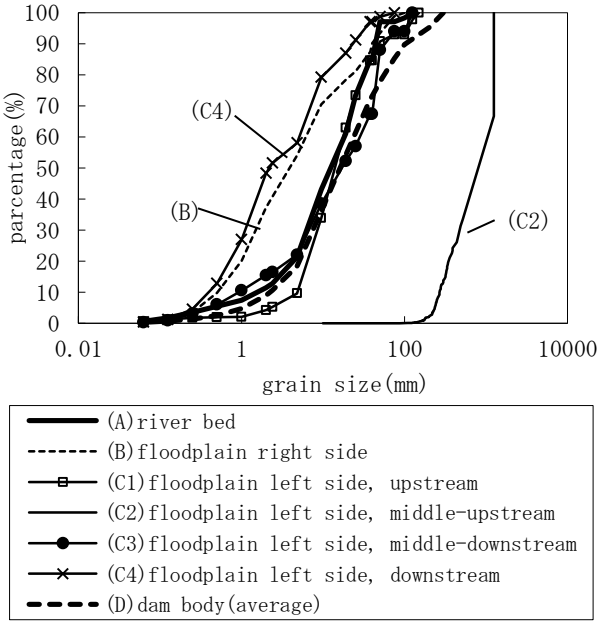

Fig.9 Grain size distribution

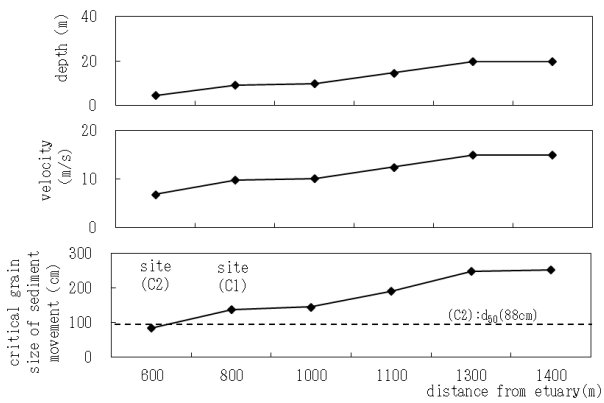

Fig.10 Longitudinal profile of hydraulic properties

4. CONCLUSION

The change of the topography and the particle size distribution associated with the large scale landslide dam outburst flood was investigated in this study. The changing trend of topography is similar with the case of the landslide dams induced by the 2008 Iwate-Miyagi Nairiku earthquake. The longitudinal profile of particle size seems to relate to the threshold of particle size of incipient motion. Based on the planar change of the particle size, we estimated the flood process on the alluvial fan. The condition of the forefront formed in the inundation area is unclear because the inundation area overlapped with sea. Hence, the accumulation of data relating to the forefront of the inundation area is one of future subjects.

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REFERENCES

Costa, J.E. and Schuster, R.I. (1988): The formation and failure of natural dams, Geological Society of America Bulletin, Vol. 100, p. 1054-1068

Ishizuka, T. and Osanai, N. (2012): Deep catastrophic landslides and landslide dams in Japan. Proceedings of international symposium on dams for a changing world, p.1-75 - 1-80

Satofuka, Y., Yoshino, K., Mizuyama, T., Ogawa, K., Uchikawa, T. and Mori, T. (2007): Prediction of floods caused by landslide dam collapse, Annual Journal of Hydraulics Engineering, Vol. 51, p. 901-906(in Japanese with English abstract)

Tabata, S., Mizuyama, T. and Inoue, K. (2002): Landslide dam and disaster, 206 pp.(in Japanese)

Takahashi, T. (1980): Study on the deposition of debris flows (2)-Process of Formation of Debris Fan- Annuals. Disaster Prevention Res. Inst., Kyoto Univ., Vol. 23B-2, pp. 443-456 (in Japanese with English abstract)

Uchida T., Matsuoka, A., Matsumoto, N., Matsuda, J., Akiyama, K., Tamura, K. and Ichinohe, K. (2009): Overtopping erosion of landslide dam at Numakura-urasawa, San- hazama river Miyagi Prefecture, Japan, Journal of the Japan Society of Erosion Control Engineering, Vol. 62, No. 3, p. 23-29(in Japanese with English abstract)

Yoshino, K., Uchida T., Tamura, K. and Kotake, T. (2010): Sediment transport of landslide dam by overtopping erosion : Analysis by LiDAR data, Journal of the Japan Society of Erosion Control Engineering, Vol. 62, No. 5, p. 27-35(in Japanese with English abstract)