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Deep Catastrophic Landslides and Landslide dams in Japan

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ABSTRACT:
The Iwate-Miyagi Nairiku Earthquake in 2008 brought heavy damage around the border of Iwate and Miyagi prefecture. A lot of landslide dams were caused by collapsed soil mass. Geographic features of the dams were surveyed. One of the landslide dams in Numakuraura-sawa caused surge flow to downstream. This was triggered by over flow and erosion of the dam and observed as the sudden increase of inflow to the Kurikoma dam reservoir in the downstream. Typhoon Talas landed at the Shikoku Island, Japan in early September, 2011 and it brought serious damage in the Kii Peninsula. Disaster caused by the typhoon was characterized that many deep catastrophic landslides occurred and it enlarged damage. In addition, deep catastrophic landslide formed several landslide dams. It was tried to simulate a debris flow prone area caused by outburst of a dam and to predict the time of overflow occurrence for mitigation to disaster due to landslide dams.

Keywords: Deep catastrophic landslide, landslide dam, Iwate-Miyagi Nairiku Earthquake, Typhoon Talas, Debris flow

1. INTRODUCTION

The Iwate-Miyagi Nairiku Earthquake in 2008 recorded magnitude 7.2, 6 upper in JMA seismic intensity (Oshu-shi, Iwate, Kurihara-shi, Miyagi). Heavy damage was brought around the border of Iwate and Miyagi prefecture. Because the hypocenter was near Mt. Kurikoma where volcanic deposition is thick, many mountain slopes collapsed.

A lot of landslide dams were caused by collapsed soil mass. In the Iwai basin of Ichinoseki-shi, Iwate and the Hasama basin of Kurihara-shi, Miyagi, landslide dams occurred intensively, and it was necessary to take an urgent action for disaster mitigation. In addition, a large scale debris flow occurred in Dozou-sawa, the upstream of the Sanhasama river, and a large scale landslide also occurred in the vicinity of the Aratozawa dam of the Nihasama river (Fig. 1).

This earthquake brought 48 sediment related disasters (24 debris flows, 9 landslides, 15 slope failures as of July 31, 2008, Sediment Control Department, the Ministry of Land, Infrastructure and Transport, MLIT) and those disasters resulted in the casualties of 13 dead and 10 missing.

Typhoon Talas landed at the Shikoku Island, Japan in early September, 2011 and it brought serious damage in the Kii Peninsula. Rainfall started on August 31 and continued for five days till September 4. Since a heavy rain continued for a long time, numbers of sediment related disaster occurred in Nara, Wakayama and Mie prefectures. It was 100 in total and it resulted the casualties of 56 dead and missing (Sediment Control Department, the M LIT, as of October 26).

Disasters caused by Typhoon Talas was characterized that many deep catastrophic landslides occurred and it enlarged damage. In addition, deep catastrophic landslide formed several landslide dams.

When a landslide dam outbreaks by overflow, there is a possibility that dreadful damage might be due to debris flow in a downstream area. In order to protect human lives from damage caused by such a phenomenon, it is very important to disseminate necessary information for early evacuation. In this paper, it is introduced the outline of landslide dams caused by the earthquake and typhoon and disaster mitigation activities as follows.

2. A LANDSLIDE DAM IN NUMAKURAURA-SAWA BY THE IWATE-MIYAGI NAIRIKU EARTHQUAKE, 2008

Numakuraura-sawa is located at the 5km upper reach of the Kurikoma dam in the Sanhasama basin (Fig. 1). A large scale landslide occurred in a mountain slope of the right bank and dammed up a stream. The photo of landslide dam is shown in Fig. 2. The gradient of a collapsed slope was approximately 35 degree, the width and the height of the landslide were approximately 400-600m and 90m. The longitudinal profile of the landslide dam taken by aerial laser survey (conducted on June 16) is shown in Fig. 3. It is before overflow on June 21. The width and the length of the landslide dam were about 150m and 550m respectively. The relative height of the dam was approximately 42m and the horizontal distance from the top to the downstream end was about 400m. The average gradient of the downstream slope was about 6 degrees. It is thought that the riverbed rose approximately 26m at the apex point of the landslide dam. The longitudinal gradient of the riverbed before the formation of the landslide dam was about 1/24 (2.4 degrees).

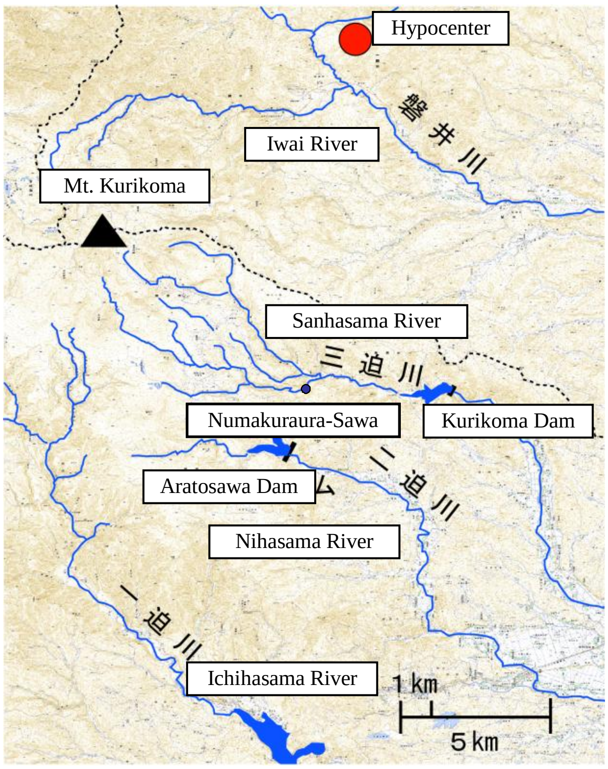

Figure 1. Location of Numakuraura-sawa

The inflow rate of the Kurikoma dam suddenly began to increase at 0:30 a.m. on June 21, 2008, and reached approximately 100m^3/s at 1:20 (Fig. 4). Afterwards, the inflow rate suddenly decreased. About two hours later, current returned to the original value. There was not post-quake and the amount of rainfall was 0mm in the Kurikoma dam basin from 20 to 21 June.

Figure 2. A photo of the landslide dam formed in Numakuraura-sawa
(Taken on July. 10, 2008)

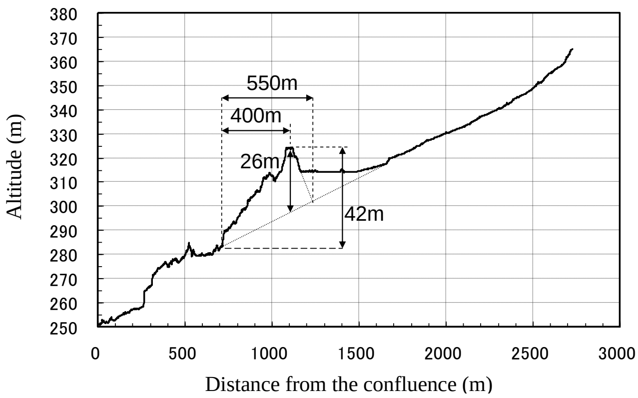

Figure 3. The longitudinal profile of the Numakuraura-sawa landslide dam

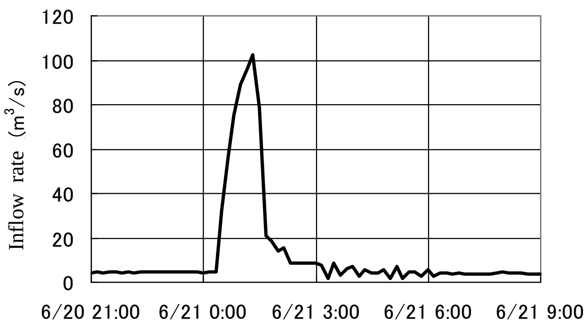

Figure 4. Inflow rate to Kurikoma dam reservoir in June 21 to 22, 2008
Revised data by Miyagi prefecture

Investigation using a helicopter was carried out in the morning on June 21, just after the phenomenon mentioned above. It was found that erosion of the landslide dam by overflow occurred and reservoir level reduced. Thus, it is considered that the discharge from the reservoir due to overflow and erosion led to the sudden increase of inflow to the Kurikoma dam.

3. LANDSLIDE DAMS CAUSED BY TYPHOON TALAS, 2011

3.1. Outline of Deep Catastrophic Landslides and Landslide Dams

In the Kii Mountains, there was disaster called the Meiji Totsukawa disaster in 1889 and so did the Aritagawa disaster in 1953. Many deep catastrophic landslides have occurred. Geology consisting of very fragile rock by faulting is distributed over the area. Sediment Control Department, the Ministry of Land, Infrastructure, Transport and Tourism, MLIT and Public Works Research Institute, PWRI made and disseminated the deep catastrophic landslide assessment map at national level in August, 2010. This area is designated as a very high risk area in the map.

The location of mountain slope collapse caused by the typhoon is shown in Fig. 5. It is specified by an aerial photo. The number of collapse found in the analyzed area was about 3,000. 70 or more are presumed to be more than 100,000 m^3 in volume and considered to be deep catastrophic landslides (Moriyama et al., 2011).

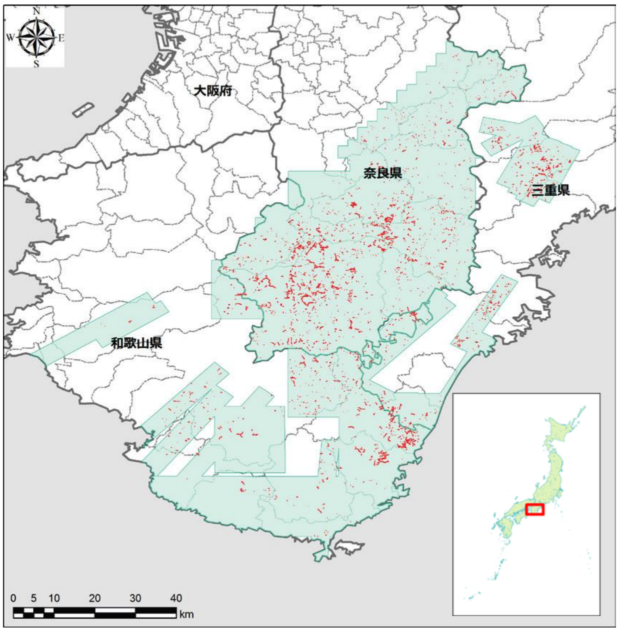

Figure 5. A map of landslides found in the post-event aerial photo survey
dots show landslides and shaded is surveyed areas

It turned out that 17 landslide dams are formed as a result of the investigation conducted just after the disaster. Among these, the five dams were so large and dangerous to overflow and outbreak. (Fig. 6 and 7) The urgent investigation based on the law enforced on May 1, 2010 was applied by the MLIT for those five dams. The objective of the law is as follows; to provide the necessary information on a hazard prone area and the time of hazard occurrence to a local government for residents' evacuation, and to clarify the role of the national and prefectural government on emergent action which requires advanced technical knowledge and skill.

Figure 6. A photo of the landslide dam formed in Nagatono
(Taken on Sept. 5, 2011)

Figure 7. A photo of the landslide dam formed in Kuridaira
(Taken on Sept. 6, 2011)

3.2. Simulation of a Debris Flow Prone Area Caused by Outburst of a Landslide Dam

The investigation using a helicopter and the satellite image were carried out for the whole region of the Kii Peninsula after the typhoon passed. Large scale landslide dams were discovered at four places, called Akatani, Nagatono, kuridaira and Iya . In the investigation by a helicopter, the designation of large scale landslide dams and the measurement of the designated dams using a hand-held long distance laser range finder were done simultaneously. Parameters needed for the simulation of an inundation area were acquired by the measurement. The one of necessary parameters is relative height of a dam and it is calculated by the difference of the elevation between the downstream end and the assumed overflow point. This method was contrived in order to acquire parameters for the prompt simulation of an inundation area (Fig. 8).

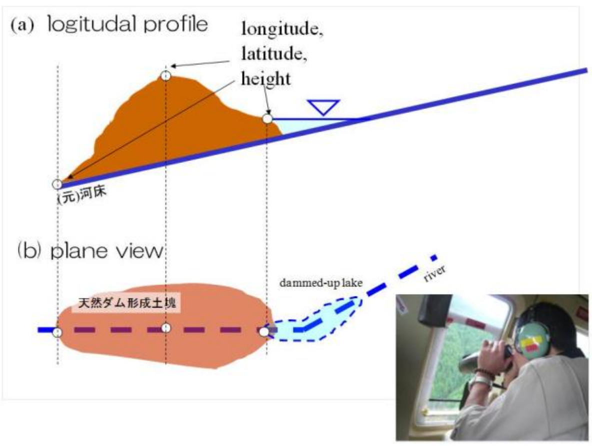

Figure 8. Procedure of setting parameters

A debris flow prone area was simulated using the technique combined one-dimensional river bed variation analysis for erosion of a dam and two-dimensional flood calculation in a downstream area (Fig. 9). This method was proposed in order to balance the two objectives, the accuracy of calculation and the reduction of calculating time. It is crucial to prepare warning and evacuation in a downstream area as soon as possible when a landslide dam appears. The result was able to be released by this method on September 8, two days after the investigation was started. An example of the result is shown as Fig. 10. The blue meshed area shown in the figure is a debris flow prone area caused by the outbreak of a landslide dam.

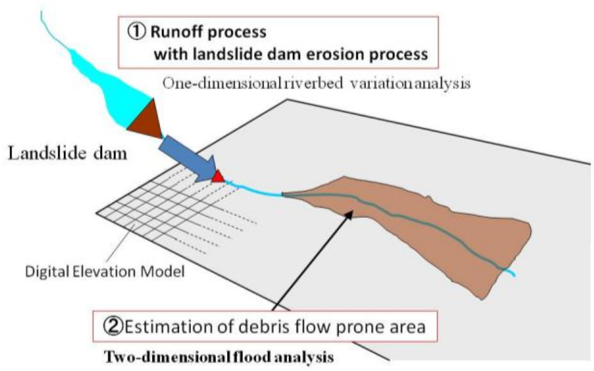

Figure 9. Conceptual Diagram of Simulation Model
Quick analysis system for debris flow
induced by landslide dam (Quad-L)

Otherwise, this calculation is considered to update the accuracy of the result gradually. At first step, a disaster prone area is disseminated using data with rough accuracy as shown in Fig. 8. Then, the more accurate information on a hazard area is provided using data taken by more detailed investigation. After the first official announcement on a possible hazard area, the detailed data about the height of the landslide dam and others were obtained using the aerial photo. So, the revised information was announced on September 12, four days after the first announcement .

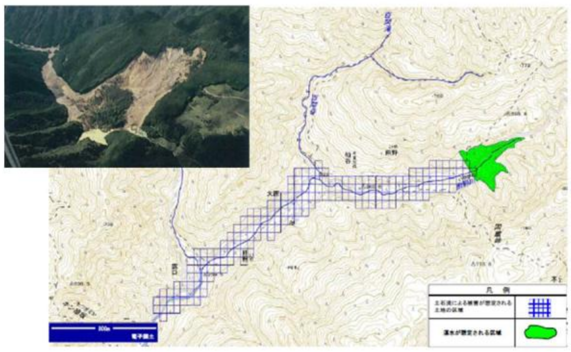

Figure 10. A map of susceptible area (Iya landslide dam)
Meshed area is for landslide dam outburst debris flow and solid area is for inundation by ponding in the upper area.

In the first investigation from a helicopter, the scale of another landslide dam (called Kitamata) was not able to be confirmed. However, it is found that the height of the dam was more than 20 m by ground survey and it started to calculate a possible inundation area. The information on hazard area as well as other landslide dams was released on September 15, two days after the survey.

3.3. Prediction of the Time of Disaster Due to Landslide Dam

Disaster caused by a landslide dam can be classified into two categories. One is induced by water dammed up in the upstream of a dam, and another is caused by surge from reservoir with rapid erosion of a landslide dam. In the former case, it obviously occurs when water level goes up. The latter case is caused when overflow starts on a landslide dam. Therefore, if water level is predicted, it is possible to infer the time of overflow and disaster occurrence for two categorized disaster.

There are several methods for prediction. At the early stage, information on topography and stream flow around a dam is not sufficient. So, the following equation could be considered;

$$T = \frac{V_t - V_r}{V_r / D} \quad (1)$$

Where T is the predicted time when a reservoir is filled by water upstream, V_t is the presumed maximum volume which a dam can reserve, V_r is the then volume of water dammed up by a landslide dam , D is duration after a landslide dam formed. $(V_t - V_r)$ means the then vacant volume of a reservoir. (V_r/D) means assumed average inflow rate to a reservoir. At the stage after some time, more accurate prediction is done by run-off analysis based on the detailed information on geographical feature, or the relation between rainfall and discharge.

In the case of typhoon Talas, the exact time of the occurrence of the landslide dams was not able to be specified. Therefore, the amount of precipitation to fill a reservoir was calculated. Essentially, effective precipitation should be used in the calculation. Since the relation between rainfall and discharge in a basin was unknown, it was assumed that the all amount of rainfall discharges in consideration of the safety side. Table 1 is the result of the calculation just after the formation of landslide dams. After the information on detailed geographical feature was acquired, the inflow rate to a reservoir was calculated with the storage function method and the time when a reservoir filled was presumed using the calculated inflow rate. Since the relation between rainfall and discharge was still unknown, general value in a small river was used as coefficients. Then, the coefficients were revised time by time based on data about the relation between rainfall and water level of a reservoir observed.

Table 1. Critical rainfall amount of the five landslide dams as of Sept. 15, 2011

Name of the place	Capacity of the dam (10^3m^3)	Catchment area (km^2)	Critical rainfall amount (mm)
Akatani	500	13.2	30
Nagatono	1,600	4.5	350
Kuridaira	5,700	8.7	660
Kitamata	20	0.35	50
Iya	10	1.2	10

Except for the landslide dam in Kuridaira, the water level of a reservoir went down when it did not rain. This is guessed because reservoir water permeated and discharged through a soil mass of the landslide dam and the quantity of discharge is more than that of inflow to a reservoir. Since such a tendency was not assumed at the beginning, it is necessary to improve the water level prediction considering the above mentioned phenomenon.

3.4. Observation of Water level of Landslide Dams

As mentioned so far, in order to mitigate the damage caused by a landslide dam, it is important to predict the time when overflow starts measuring the water level of a reservoir. Since a landslide dam mainly occurs in a mountain area, surrounding geographic feature is very steep and a road does not exist in many cases. Traffic may be obstructed due to slope collapse. Therefore, the transportation of equipment and communication is very difficult and it is necessary to solve such a problem for measurement. The Public Works Research Institute had developed an aerially-conveyable floating water level gauge for the above objective (Itou et al., 2009).

The water level observation buoys were dropped from the air, and installed for four landslide dams (Akatani, Nagatono, Kuridaira, Iya) (Fig. 11). The measurement result is shown in Fig. 12 (in Akatani). From the predawn on September 22, water level became high gradually and decreased rapidly on the same day after 10:00. It was guessed overflow and erosion started on the landslide dam. It was confirmed by helicopter survey that overflow and erosion had occurred actually (Fig. 13).

Figure 11. An aerially-conveyable floating water level gauge

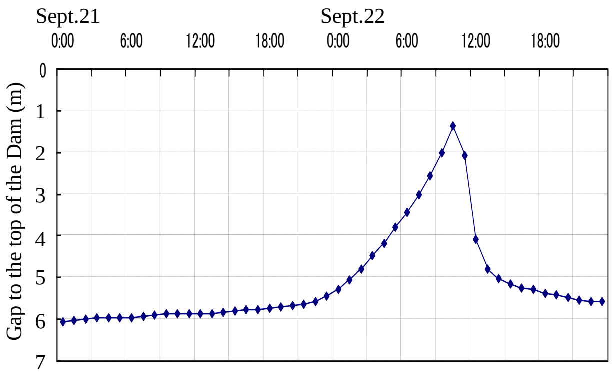

Figure 12. An example of water stage data (Akadani landslide dam)

Figure 13. Photos of the Akadani landslide dam
Before over flow (above) and after overflow (below)

4. CONCLUSION

For the landslide dam formed by the Iwate-Miyagi Nairiku Earthquake, it is introduced the geographic features and the situation when overflow and erosion of the dam occurred. The sudden discharge by overflow and erosion of the dam was observed as the rapid increase of inflow rate to the Kurikoma dam reservoir in the downstream.

In the case of Typhoon Talas, many deep catastrophic landslides and landslide dams also occurred. For the disaster mitigation, it was made effort to calculate a disaster prone area and predict the time when disaster occur. The result was officially announced to a local government for residents' evacuation. A method of calculation was proposed for the objective to balance the accuracy of calculation and the reduction of calculating time. It is important to prepare warning and evacuation in a downstream area as soon as possible when a landslide dam appears.

There are many susceptible areas to large scale sediment induced disaster like deep catastrophic landslides and landslide dams in Japan. People were suffered from disaster repeatedly according to an ancient record. It is crucial to make further effort to advance the method like simulation for disaster prone area, the prediction of disaster occurrence and monitoring system.

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