Disaster Report

Survey Report of Sediment Disaster in Aranayake, Sri Lanka, on May, 2016

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A large-scale sediment disaster occurred in Aranayake, Kegalle District, Sri Lanka, on 17 th, May, 2016, due to the heavy rainfall from the 15th May, 2016. The damage from the heavy rainfall is as follows (DMC (Disaster Management Centre) Situation Report as at 9 : 00, 13 th Jun, 2016). The number of deaths is 31 people, and 96 peoples missing at Aranayake. Therefore to understand the overall disaster situation of the sediment disaster area, we conducted an aerial survey by using a Sri Lankan Air Force chopper on 22 May and field survey on 8th to 9th and 21st to 22nd Jun as JICA (Japan International Cooperation Agency) Survey team. Further, we conducted numerical simulation to understand processes of this sediment disaster. In this report, we compiled two kinds of survey results and a proposal about the improvement of sediment disaster countermeasures in the future.

Key words: sediment disaster, debris flow, Landslide Hazard Zonation Map, simulation software “KANAKO”

1. PREFACE

In Sri Lanka, a large-scale sediment disaster occurred in Aranayake, Kegalle District, on 17th May 2016. According to Disaster Management Centre (DMC) under the Ministry of Disaster Management (MoDM), this sediment disaster caused 31 dead and 96 missing persons. JICA's the technical cooperation project : Technical Cooperation for Landslide Mitigation Project (TCLMP) organized an investigating team with disaster management organization for grasping the field situation. This report summarized disaster record as basic document at the time of the disaster response for the future. The investigating team carried out aerial survey for grasping whole disaster situation on 22nd May, and two field surveys on 8th to

9th and 21st to 22nd June. Further, we conducted numerical simulation to understand processes of this sediment disaster using 1 D and 2 D debris flow simulators. This report was compiled from these survey results and a proposal about the improvement of sediment disaster countermeasures in the future.

2. SUMMARY OF THE RAINFALL AND DISASTER

2.1 Rainfall situation

A low pressure (Tropical cyclone) closely passed through Sri Lanka from south to north during 15th to 17th May. According to the announcement document of the National Oceanic and Atmospheric Administration in U.S. on 14th May 2016, a weak

depression with a central pressure of 1006 hPa was generated 150 km away from southeast Sri Lanka over the Indian Ocean. It slowly moved towards the north along the eastern coast of Sri Lanka causing heavy rainfall. This low pressure went to north after 18th May while reducing central pressure and affected damages to Bangladesh, India and Myanmar.

Fig.1 illustrates the accumulated rainfall distribution from 12th to 18th May. The maps were made out of the data obtained from the manual rain-gauge observations weather stations of the Department of Meteorology (DoM) and voluntary observation stations (approximately 180 stations in total). The rainfall started on 13th May and reached its peak on 15th May. During this time an amount of accumulated rainfall from 200 to 373 mm were recorded in the northeastern and central regions. The rainfall became to weaken from 16th May, and several heavy landslides occurred in Kegalle and Kandy Districts starting from the night of 16th May to the morning of 17th May. Flooding also supposed to starting many areas from the 16th May and the Kelani River around Colombo City started to inundate from 18th May.

According to the observed precipitation data from 1960 to 1990 by the weather station of DoM which is the nearest to Aranayake, the average annual precipitation is 1,840 mm and the average monthly precipitation in May is 144 mm. That indicates that this rainfall due to the low pressure was very serious.

2.2 Topography and geology

The landslide slope is facing north. That slope consists of hard bedrock of granitic gneiss-muddy

gneiss. It is coincide with the ridge shape geographical feature in the surrounding area.

National Building Research Organization (NBRO) had made a Landslide Hazard Zonation Map (LHZM) as shown in Fig. 2. NBRO developed LHZM on 10 districts in central mountain area that has high risk of sediment disaster. LHZM divided the risk into four categories by statistical method based on six factors such as land-use, slope angle, soil and geological features, topography etc. This Aranayake landslide had occurred in the most dangerous area which is categorized as “Landslide are most likely to occur” in LHZM.

3. MECHANISM OF THE DISASTER OCCURRENCE THROUGH FIELD SURVEY

3.1 Interviews with inhabitants

Considering the result of interviews with inhabitants “the landslide occurred more than twice”, it was estimated that the landslide occurrence process of the evening at 17th May is as follows :

- The landslide occurred in the upper slope in the evening.
- The landslide moved down and flow out from the downstream of nick line (the turning point of the

Fig.1 Accumulated rainfall from 12 th to 18 th May, 2016

Fig.2 Landslide Hazard Zonation Map prepared by NBRO

slope degree) of “the Upper Slope”.

- (c) The landslide sediments became a debris flow and stopped once in “stream part” and around “Outlet Part” in Fig. 3. A landslide dam developed by these collapse sediments.
- (d) At midnight, the landslide dam collapsed due to the ponded water, and water and deposited soils flowed to the paddy area in “the Lower Flat Part”.

3.2 Topographic Analysis and Field survey

3.2.1 Method

Grasp of the landslide affected area and estimation of soil movement conducted based on the aerial photo taken from the helicopter survey on 22nd May and the result of LiDAR (Light Detection and Ranging) survey. That LiDAR survey was implemented in December 2015 by the Survey Department of Sri Lanka under

the JICA's Development Survey “Capacity Development Project for Creating Digital Elevation Model Enabling Disaster Resilience”. This terrain data provided as DEM (Digital Elevation Model) format which excluded the surface coating (like vegetation and houses). On the other hand, the result of the aerial photo analysis was developed as DSM (Digital Surface Model) format which includes the surface coating.

Above this, an estimation of soil movement was calculated by comparison of topographic difference between before and after landslide. This result and the surface outflowed area are shown in Fig. 3.

The accuracy of aerial photo analysis is normally improved by using GPS or air marks. But this survey aimed to conduct for an emergency response so that it was difficult to set air marks. Therefore, the bench marks for the topographic analysis used given points

Fig. 3 Landslide overview (Left) and height change estimation (Right)

taken from the photograph such as intersection, house, and tree. The topographic correction was conducted to be consistent with the actual conditions of the deposition through the site survey.

The entire affected area from the main scarp to the end part of the landslide has a maximum width of about 500 m and a length of about 2,000 m. The target slope is classified by three areas into “Upper Slope” which is the main collapsed part, “Stream Part” and “Lower Flat Area” which has thinly spread mudflow sediments.

3.2.2 Results

(1) Upper slope (Cf. Fig. 3)

Length is 1,100 m, maximum width is about 500 m. The “Upper Slope” was subdivided into “Near the Scarp”, “Upper part of Outcrops” and “Lower Part of Outcrops”.

Fig.4 shows the result of topographic analysis on the main scarp. It was approximately 25 m in depth. The amount of collapsing sediment was roughly estimated to be around 200,000 m³ at “Near the Scarp”.

The original slope angle before the landslide was around 25–30 degree by LiDAR survey. In “Upper part of Outcrops”, soils and weathered bedrock was removed due to landslide, thus most of area was degraded. The collapsing sediments have been stopped to flow down while repeating the deposition and erosion because a steep slope and a gentle slope were

mixed in the “Lower part of Outcrops” (as referred Fig. 5).

The deposition of sediment in about 1–5 m was confirmed at the left side of the “Lower Part of Outcrops”. Moreover, the super elevation of outside of bank could be observed (Photo 1), suggesting that the sediment quickly flowed down this part. That sediment still remains on the slope as of end of December 2016.

(2) Stream part (Cf. Fig. 3)

Length is 500 m and width is about 100 m. “Stream Part” was subdivided into “Narrow Part” and “Outlet Part”. As the result of photo analysis, the deposition depth of sediments is estimated to be approximately 2–5 m at the “Narrow Part” (as referred Fig. 6). A large boulders (>1 m) were included in the deposited sediment. These results suggest that the deposited sediment was transported as debris flow. Further, the eroded channel could be observed in this part (Photo 2). This indicates that the deposited sediment was eroded due to secondary flow after the sediment flowed as debris flow was deposited. The deposition depth about 10 m and maximum 5 m of boulders was confirmed at the “Outlet Part” by site survey (Photo 3). The amount of deposition was estimated to be around 120,000 m³ in this part.

(3) Lower flat part (Cf. Fig. 3)

Length is 400 m, width is about 200–350 m. The result of the site survey, most debris flow including

Fig.4 Longitude Profile A-A'

Fig.5 Cross-section B-B'

Fig.6 Cross-section C-C'

Fig.7 Cross-section D-D'

boulders has stopped at the “Outlet Part”. But three days continuous rainfall was over 300 mm when the landslide occurred. The fine textured soil has outflowed and deposited in the flat area (Photo 4). The result of photo analysis indicated that the thickness of the deposited sediment was 0.5~1.5 m in “lower flat part” (as referred Fig. 7). The surface of deposited sediment was almost flat, suggesting that the deposited sediment was transported as mudflow. The amount of deposition was estimated to be around 80,000 m³ in “lower flat part”.

3.3 Mechanism of the sediment movement

The mechanism of this sediment movement is considered to be the following at present as a result of a field survey and data analysis.

It is estimated that the landslide occurred from about 16:30 to 17:30 on 17th May. Firstly, the landslide occurred in the topmost steep slope, and the sediment become debris flow in “Upper part of Outcrops” and “Lower Part of Outcrops”. Then it reached to the “Stream Part” and stopped moving. The total rainfall for three days on the 15th to 17th May just before the landslide occurred was more than 300 mm. Therefore, it is considered that the sediments by the landslide at the topmost part of the slope were

mixed with a lot of surface water and groundwater. It is considered that the debris flew out to the lower part with surface water in accordance with the geographical shape as well. This was proved that continuous spring groundwater at the top of the landslide was flowing down through surface toward the lower part by the field survey.

Deposition of big boulder (maximum diameter almost 5 m) is restricted inside the upper slope and along the stream part. On the other hand, only the fine sediments have reached the “lower flat part”. Therefore this was proved from the landslide which became debris flow, and stopped in the “stream part” once, and after that the deposited sediment which contains a lot of water moved again.

4. VERIFICATION BY THE NUMERICAL SIMULATION

At the dispatch of the TCLMP as the third short-term expert, we carried out an exercise for estimation of the affected area of debris flow using Japanese simulation software for debris flow propagation and deposition. Thus, we checked the applicability of the numerical simulation for this disaster before the exercise. Moreover, we applied physically-based

Photo 1 “Lower Part of Outcrops”

Photo 3 Big bolder confirmed at “Outlet Part”

Photo 2 Condition of stream after secondary erosion

Photo 4 “Lower Flat Part” affected by mudflow

numerical simulation model to describe the area affected by debris flow in Aranayake to verify the insight of disaster processes from field survey.

This disaster is confirmed to be a debris flow due to a large-scale landslide. It is thought that the wide range grain sediment was taken in and moved in the large-scale debris flow. Previous studies indicated that the fine sediment in large-scale debris flow behave like fluid, not solid [e.g., Nishiguchi et al., 2011]. This process is called as “phase-shift” of fine sediment. Moreover, previous studies reported that due to phase-shift of fine sediment in debris flow, the fluidity of debris flow became large and the affected area was extended [e.g., Nishiguchi et al., 2011].

Based on the above, we tried the reproduction of the phenomenon using a one-dimensional debris flow simulation program that could consider the changes of flow condition from debris flow to normal turbulent flow developed by Uchida et al. [2013]. Moreover, this program was included the processes of phase-shift of fine sediment.

Field survey clarified there are two main flow paths (as referred Fig. 8). So, we calculated debris flows by dividing the area into left and right flow paths. In addition, we set the length of the slope and width of landslide from the result of the field survey, and calculated the volume of sediment flowed into each flow path. Parameter values that we set are shown in Table 1. The ratio of phase-shifted fine sediment behaves like fluid set by trial and error. We changed the ratio of fine sediment in the range from 0.2 to 0.4, according to the previous study by Nishiguchi et al. [2014] who argued that the ratio of fine sediment in large-scale debris flow might be around 0.4. We set a supply hydrograph at the upper end of calculation section, according to “calculation manual for flowing down and flooding of debris flow due to deep-seated landslide (draft)” published by Public Works Research Institute. The manual showed the hydrograph estimated method based on the assumption that the longitudinal shape of debris flow at the upper end of calculation section was the same as that of landslide mass. Unfortunately, there is inadequate information about sediment characteristics such as the particle size of sediment, an internal friction angle of sediment, the mass density of sediment, thus, we set ordinal values in Table 1 in reference to a disaster example of the previous debris flow simulation in Japan [e.g., Nishiguchi et al., 2014].

The calculation result is shown in Fig. 9 and Fig. 10. At both flow paths, it has a tendency that erosion occurs in the upper slope and large deposits occur near the narrow part of stream part. This trend agreed well with the results of field survey that 1) sediment flow down as debris flow to the narrow part of stream part,

and 2) large portion of sediment deposited at the stream part.

In the case of debris flow flowing down an indistinct valley like this disaster, it is difficult to set a flowing range for 1D simulation before debris flow

Fig.8 Target area of debris flow simulation

Table 1 Parameter of debris flow simulation

Parameters	Value
Density of water (t/m^3)	1
Density of sediment (t/m^3)	2.65
Gravitational acceleration (m/s^2)	9.8
Coefficient for erosion velocity	0.0007
Coefficient for deposition velocity	0.05
Sediment concentration of river bed	0.65
Friction Angle (degree)	35
Switching of deposition velocity equation =0: dividing by flow depth =1: dividing by grain size diameter	1
Pre-calculation period (sec)	0
Length of time step (sec)	1
Minimum water depth for calculation (m)	0.01
The ratio of fine sediment to sediment concentration before erosion	0.3
The ratio of fine sediment to sediment concentration after erosion	0.3
The ratio of fine sediment to sediment concentration before erosion	0
Coefficient of whether or not fine sediment is taken into the pore after deposition	0
Maximum interstitial fluid density including fine sediment	1.625

occurrence. Therefore, we also carried out calculation using the two-dimensional debris flow simulation to describe spatial pattern of debris flow propagation. Here, we used a widely-used two-dimensional debris flow simulation “Hyper KANAKO” developed by Horiuchi et al. [2012] which can calculate the flowing range of the debris flow by using LiDAR data. The Hyper KANAKO was based on the concept of stony debris flow, sediment sheet flow and bedload proposed by Takahashi and his colleagues [e.g., Takahashi, 2009]. The Hyper KANAKO has already been combined with a graphical user interface to allow engineers to use it.

The parameters for sediment characteristics and input hydrograph used the same as the above-mentioned one-dimensional simulation (as referred Table 1). We set interstitial fluid density to consider effects of phase-shift of fine sediment. Two-dimensional calculation was started from near the lower end of “near the scarp” show in Fig. 3. Grid cell size of two-dimensional calculation was 10 m.

Fig.11 shows the depth of the water flow 600 seconds after debris flow occurred. The result was

generally agreed well with the observation in terms of spatial pattern of flow propagated area. The calculated debris flow is divided into two main flow paths, flows down and stops near the “Lower Flat Part”, is reproduced.

Here we confirmed the following points. The one dimensional debris flow simulation included in the process of phase shift of fine sediment might be effective to describe what the sediment deposited “Narrow Part” by expressing the phase shift of fine sediment due to large scale landslide. Furthermore, the two dimensional debris flow simulation might be effective to express the spatial patterns of debris flow due to large scale landslide. However, in these simulations, we did not consider effects of landslide dam to extend damaged area. Thus, in both simulations, we were not able to express the expanse of the debris flow, while it was flowing down and depositing.

5. SUGGESTION ABOUT THE FUTURE RESPONSE

From this disaster, some issues became clear about response and preparedness of NBRO for sediment disasters.

The landslide occurred at the most dangerous in four categories in LHZM which was developed by NBRO. In this means, it may be said that NBRO could identify the outbreak point of sediment disaster by LHZM. However, unfortunately LHZM could not predict the affected area of debris flow. It is not limited only in Sri Lanka, the sediment disaster was classified as “Landslide” in many countries, and also the phenomenon called “debris flow” in Japan are not clearly classified. In the some report of researchers in NBRO, the range flowing down of the sediment had been studied as the “Most possible paths of Landslides”. But the progress of the subsequent study has not been confirmed. Therefore, after aerial survey, we suggested that it is needed to identify the affected area caused by debris flow at the meeting of relevant ministries and agencies led by the MoDM on 23rd May. The meeting was held for discussing countermeasures of this sediment disaster including inundation damage on the Kelani River. In NBRO, a trial to identify the range flowing down of the debris flow using numerical simulation had begun as Build Back Better of this disaster. Therefore, in the invitation of TCLMP second short-term expert on August 2016, we gave the technical guidance about the prediction method of the affected area by debris flow. Furthermore, in the invitation of the TCLMP third short term experts on January 2017, we conducted exercise of setting method of the Yellow Zone based

Fig.9 Result of one-dimensional riverbed change calculation of left branch

Fig.10 Result of one-dimensional riverbed change calculation of right branch

Fig.11 Simulated Result of flow depth 600 seconds after debris flow occurrence using two-dimensional debris flow simulator "Hyper KANAKO"

on the Sediment disaster prevention Act in Japan, and prediction method to estimate the affected area of debris flow by using numerical simulation applicability which had been confirmed in the preceding chapter. The parameters to use for simulation are important to repeat field survey and calculation, and to grasp the value of parameters suitable for Sri Lanka. In addition, it is important to make use of parameters for the prediction of the affected area of the debris flow. For this purpose, continuous cooperation of Japan will be necessary in future. Unfortunately, a large number of people have died in this Aranayake disaster, but, with this disaster as a start, it is expected that the sediment disaster response system in Sri Lanka was strengthened more.

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