Disaster Report

Disaster Report of Koslanda Landslide in Sri Lanka on October 29, 2014

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On 29th October, 2014 during a heavy rain event, a large landslide occurred in Koslanda, Badulla District, Sri Lanka. The landslide and associated debris flow destroyed several houses and killed more than 30 people. Following the landslide, an aerial survey by helicopter on 5th November, 2014 and field survey on 19th and 20th November, 2014 were undertaken by JICA (Japan International Cooperation Agency) Project Team to understand the occurrence mechanism of the landslide and identify further hazard of the landslide. Further, we conducted numerical simulation to understand processes of these sediment disasters. This report summarizes the observation results conducted by the JICA Project Team, presents the geological explanation of the mechanism and causes of the landslide, and gives suggestions on emergency mitigation measure for further movements of the landslides.

Key words: landslide, debris flow, aerial survey, numerical simulation

1. PREFACE

The Sri Lankan annual rainfall pattern is greatly influenced by the two monsoon seasons in the year, and it is divided into four periods.

From December to February (the northeast monsoon period: Maha), a monsoon blows from the northeast and brings rain to the east side of the island. From March to April (the inter-monsoon period), showers and thunderstorms occur frequently around the southwestern area with the northing of the equatorial depression. From May to September (the southwestern monsoon period: Yala), there is rainfall on an average of 1,000-3,500 mm per year in the southwestern part. The central highlands also have almost the same amount of rainfall caused by monsoon. From October to November (the inter-monsoon period), there is rain throughout the island by outbreak of a cyclone. Under the influence of such a climate, sediment disasters occur in an average on approximately 50 places per year on the mountainous area in Sri Lanka (from data of National Building Research Organisation: NBRO). On 29th October, 2014, a landslide disaster occurred in Koslanda, Badulla District, Uva Province (Fig. 1), central part of the Sri Lanka. Koslanda is located in the south end mountainous area on the central part of Sri Lanka (c.f. Situation Report of Disaster Management Centre (2016)). In Koslanda, there is a wet season from December to February under the influence of the northeast monsoon. Sediment disasters such as landslides and debris flows mostly occur during this period.

Three of the authors (Mr. Handa, Mr. Hara and Mr. Okawara) were dispatched to Sri Lanka for “Technical Cooperation for Landslide Mitigation Project”, and conducted an aerial survey with Mr. Shimano: JICA Sri Lanka Office and officers of Disaster Management Centre (DMC) and NBRO, Ministry of Disaster Management.
Management (MoDM) in Sri Lanka on 5th November just after the disaster outbreak (c.f. 5th November 2014, Helicopter Survey Report on Badulla Koslanda Landslide, JICA Sri Lanka Office (2014)). After that, we conducted a field survey on the 19th and 20th November to confirm a more detailed site condition (c.f. 25th November 2014, Survey Results of Koslanda Landslide (2nd Report), JICA Sri Lanka Office (2014)). We also interviewed local residents to clarify the time series phenomena of the disaster and conducted numerical simulations to discuss possible physical processes of the disasters.

2. SITUATION OF LANDSLIDE OCCURRENCE AND DAMAGES

2.1 Results of interview survey

Based on the interview with local residents, we thought the event occurred in the following progress.

1) Slow-moving landslide activity was recognized in 2005 and local governments inform the danger to the inhabitants. In addition, NBRO conducted a field survey in those days and prepared a report.

2) Three days before the landslide occurred, a crack was confirmed in the road surface of the landslide head. The three days precipitation was more than 300 mm until the landslide occurred.

3) The road surface at the side of the landslide head had begun to rise around 30 cm about 6:00 on 29th October. Just after that, a huge rock fell from the upper part.

4) While trees under the road began to fall slowly, board-formed huge sediment became loose and fell from the scarp.

5) The spurts of groundwater at the upper slope (near the toe of the landslide) and a landslide took place around 7:15.

6) The whole mass of the landslide started to move down slowly.

7) The landslide mass became fluidized by a lot of groundwater and surface water in the middle slope.

8) Once fluidized, the landslide mass transformed into debris flow and moved rapidly downslope (the upper section of the debris flow area).

9) The debris flow contained some boulders with a diameter around 5 m. The temple and houses located in the middle slope were destroyed, and the debris flow reached the road (c.f. Yellow line in Fig. 2) across the lower slope.

10) The landslide mass and debris flow materials mostly accumulated on the gentle slope above the road (near the old tea factory and the cricket ground), and partially flowed down along the valley in the lower slope and into the Eruwendumolla Oya river (around 7:30).

11) There is a lot of different witness information after 7:15, therefore the actual end time may vary.

12) Plural victims were discovered by the later rescue operation near the flat area where there was a...
staff house (three tenement houses) and an old cricket place. As of 20th February 2015, dead persons were 13 people and missing persons 24 people. The total victims were 37 people.

2.2 Results of field survey
The landslide slope was divided into the following three parts from the result of field survey and topographic situation. (Fig. 2 and Photo 1)

2.2.1 The upper slope
The landslide was approximately 100 m in width and 260 m in length with an average depth of about 15 m (estimated from the height of the head scarp). The landslide mass was roughly estimated to be about 260,000 m$^3$. Half of the collapse sediment remained on the upper slope from the estimation by the viewing of the field survey on 19th November, 2014 and the topography change (Fig. 4).

2.2.2 The middle slope (the upper section of debris flow area)
This area was about 150 m in width and 330 m in length, and had a maximum sediment thickness of about 5 m (near the gentle slope above the road). The amount of the debris flow deposits within the middle slope was roughly estimated to be about 150,000 m$^3$. Therefore it is thought that most of the landslide sediment from the upper slope stopped here. The deposits included some large boulders (diameter around 5 m).

2.2.3 The lower slope (the lower section of debris flow area)
The area was about 30 to 40 m in width and had an average sediment thickness of about 3 m (estimated from bank erosion). Because large boulders stopped in the middle part of the slope, it is thought that the moving mass at the lower part of the slope consisted of mainly fine sediment and muddy water. The front of the movement mass reached the main river while eroding the valley bank. The outflow of the sediment downstream from here was not confirmed.

2.3 Processes of the landslide and debris flow
From the results of the interview and field survey, the processes and mechanisms of the landslide and debris flow occurrence is thought to be as follows (Fig. 3 and Fig. 4).

Photo 1 Overview of landslide from opposite side

Photo 2 Infiltration water into the landslide crown area and small pond

Fig. 3 Condition of landslide movement (Aerial photograph taken by helicopter survey on 5th November 2014)
1) The landslide occurred within the eastern part of the landslide topography or a previous landslide block that was about 280 m wide.

2) The top of the slope around the crown area was exposed with biotite gneiss which is the metamorphic rock of pre-Cumbria times, and formed a water-catchment shape. A large amount of rainwater and groundwater accumulated in the previous days, then flowed into the landslide area from the upper slope (Photo 2).

3) The landslide mass became saturated, leading to rapid instability of the landslide area. As a result, tension cracks were developed and expanded around the road on the upper slope, while the spurs of groundwater near the toe of the landslide and collapse took place at about 7:15. The whole mass of the landslide subsequently started to move downslope.

4) Subsequent to movement towards the middle slope, the landslide mass became fluidized by a lot of groundwater and surface water, and then changed into debris flow. The debris flow moved rapidly downslope, destroying the temple and houses located near the middle slope and extending into the road across the lower slope (Photo 3).

5) A hill (remaining trees) of about 10 m of difference in elevation and a gentle slope (the old cricket ground) are present above the road (Photo 4). Most debris flow materials (including large boulders of 5 m in size) deposited within the hill and gentle slope because of a lower velocity. But the high mobility debris flow composed by fine sediments continued down through the valley in the lower slope and directly entered the river at the lowermost slope (Photo 5).

6) The amount of sediment that reached the river was very small. Therefore it was considered to be much less likely to form a landslide dam in the river and to flow further downstream.

7) It was observed that landforms would be formed by previous landslide activity at surrounding slope. It can be though that several landslides occurred
at this area in the past. In addition, new cracks existed around the head of scarp and some small collapses were also considered to be likely to occur. However, field survey and questioning from local residents indicated that no significant ground deformations occurred within the previous landslide blocks interpreted by topography.

3. VERIFICATION BY THE NUMERICAL SIMULATION

3.1 Strategy of numerical simulation

In this disaster, it is thought that fluidized landslide sediment became debris flow. Previous studies showed that runout processes, such as travel distance of debris flow, erosion and deposition patterns, of landslide incurred debris flow has been described by a debris flow simulation [e.g., Egashira et al., 1998; Nishiguchi et al., 2011; Uchida et al., 2017]. We tried to describe the debris flow processes by using the one-dimensional debris flow numerical simulation program, Kanako-LS. The Kanako-LS could describe three flow conditions, debris flow, immature debris flow and turbulent flow. The Kanako-LS originally targeted landslide induced debris flow. To describe landslide induced debris flow, the Kanako-LS included effects of phase-shift of fine sediment from solid to fluid. We considered the Kanako-LS would be applicable to describe debris flow in Koslanda. Details of the program can be found in a previous report [e.g., Uchida et al., 2013].

3.2 Data and method of numerical simulation

We identified the area that debris flow flowed down, i.e., debris flow path, and set the width and longitudinal gradient of the debris flow path from DEM data which made from the ALOS (Fig. 5). We targeted the lower end of the landslide to the lower end of the debris flow deposit. We used the value of the collapse quantity, width and length to set a hydrograph and sediment discharge of the upper end of the calculation section. We assumed landslide mass was fully saturated and only groundwater included in the landslide mass contributed to debris flow. We set input hydrograph and sediment discharge used the method proposed by Nishiguchi et al. [2011]. Deposition velocity equation used the formula obtained by dividing unit width flow rate by particle size. Other used parameter values are shown in Table 1.

| Parameters                                      | Value  |
|------------------------------------------------|--------|
| Density of water (t/m³)                        | 1.07   |
| Density of sediment (t/m³)                     | 2.65   |
| Gravitational acceleration (m/s²)              | 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     |
| 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 deposition | 0.3  |
| Coefficient of whether or not fine sediment is taken into the pore after deposition | 0    |
| Maximum interstitial density including fine sediment | 1.625 |
3.3 Results and discussions

The calculation result (Case-1) is shown in Fig. 5. The debris deposited more than 10 m at the upper part of the middle slope immediately below the landslide scar, and almost all debris deposited on the middle slope, and did not arrive at the main stream. This agreed well with the field survey that showed most of the runout sediment was deposited on the middle slope.

However, it was not able to describe debris arriving at the main stream. There are several possible explanations for this discrepancy between the field survey and numerical simulation. First, the additional surface water flow might contribute to the extension of the affected area, although we did not input surface water in this simulation. Second, debris flow was divided into two paths (Fig. 6), although we assumed a single flow path in the simulation. Refer to the Fig. 6, we set wider river width of average 60 m and narrower river width of average 20 m on the right path and narrowed the river width on the left path in the steepest angle along the valley. The parameter for calculation used the same value as mentioned in Table 1, and set the quantity of collapse as half of the calculation of Fig. 5. The calculation result is shown in Fig. 7 (Case-2). In the right bank side, the result is that most debris deposited on the middle slope and debris did not arrive at the main river. On the other hand, in the left bank side, debris flow travelled to the main river.

We don’t have any information about number of debris flow surges in Koslanda. However a number of disaster reports in Japan showed several debris flow surges occurred in a single event [e.g., Nishiguchi et al., 2011; Uchida et al., 2017]. From these evidences and results of the simulation, in Koslanda, multi debris flow surges might occur and the flow path of later debris flow surge might be affected by the topographic change due to deposition of the first debris flow surge.

However, by calculation using simulation software, it was confirmed that we could estimate to some extent that it was not able to be estimated only by field survey. Because we used the Japanese parameter value in this simulation, it is hard to say that the parameter is suitable for Sri Lanka. Therefore, it is necessary to research the parameter that is suitable for Sri Lanka, and cooperate with NBRO more in future.

4. SUGGESTIONS ABOUT THE FUTURE RESPONSE

Based on the above field survey as mentioned in Chapter 2 and 3, we proposed the following suggestion to the secretary of MoDM and related officer as an emergency response on November 2014.

(1) Structural Mitigation Measures
1) Implementation of a drainage channel within the landslide area to collect surface and subsurface water and to drain it away from the landslide area, and of drainage channels outside the landslide area to prevent surface water from flowing into the landslide area.
2) Emergent restoration of the road crossing the lower slope of the landslide area, including some lifelines such as electrical cable, pipe line etc.
3) Implementation of emergency earth retaining work (gabion wall) on the mountain side of the road across the landslide in order to prepare space for deposition of further landslide materials.
Non-Structural Mitigation Measures

1) Installation of rain gauge and establishment of warning control values to prevent human casualties during the road restoration (To conduct road stoppage when the precipitation exceeds the threshold limit).

2) Formulation of the warning and evacuation plan of landslide disaster focusing on the local residents (Confirmation of the information dissemination system, identification of a concrete place of refuge).

3) Implementation of disaster education to local residents and tea factory workers (About the present response before carrying out landslide measures).

There was an opportunity to conduct a field survey as part of training for landslide identification using topographic map with DMC and NBRO officers on 23th to 24th January, 2015. Further experiences of field survey of disasters would develop experts for sediment disasters in Sri Lanka. It was a good opportunity to introduce the survey method carried out at sediment disasters in Japan by this aerial and field survey.

It is necessary for continuously discussion and examination with counterparts for the suitable method in Sri Lanka for implementation of these responses by themselves. In addition, we conducted a debris flow simulation, but it was difficult to reproduce the phenomenon with only a few examples. Therefore, we confirmed that continuous research and study under collaboration with counterparts is required for the parameter settings in Sri Lanka. Technical cooperation regarding sediment disaster prevention between Sri Lanka and Japan should be done continuously in future.

REFERENCES

Disaster Management Centre (2014) : Situation Report, as of 5th November 2014
JICA Sri Lanka Office (2014) : 5th November 2014, Helicopter Survey Report on Badulla Koslanda Landslide (https://www.jica.go.jp/srilanka/english/office/topics/c8h0vm00008zvx2k-att/press46_01.pdf)
JICA Sri Lanka Office (2014) : 25th November 2014, Survey Results of Koslanda Landslide (2nd Report) (https://www.jica.go.jp/srilanka/english/office/topics/c8h0vm0000909h19-att/press141125_01.pdf)
Egashira, S., Honda, N., Miyamoto, K. (1998) Numerical simulation of debris flow at the Gamaharazawa in the Hime river basin, Annual Journal of Hydraulic Engineering, 42, 919-924 (in Japanese).
Nishiguchi, Y., Uchida, T., Tamura, K., Satofuka, Y. (2011). Prediction of run-out process for a debris flow triggered by a deep rapid landslide, Proceedings of 5th Debris Flow Hazard Mitigation Conference, 477-485.
Uchida, T., Nishiguchi, Y., Nakatani, K., Satofuka, Y., Yamakoshi, T., Okamoto, A. (2013) New Numerical Simulation Procedure for Large-scale Debris Flows (Kanako-LS). International Journal of Erosion Control Engineering, 6, 58-67.
Uchida, T., Nishiguchi, Y., Matsumoto, N., Sakurai, W. (2017) Observation and numerical simulation of debris flow induced by deep-seated rapid landslide, in Advancing Culture of Living with Landslides, M. Mikos et al. (eds.), Vol. 4, 399-405

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