Survey Report of Sediment Disaster in Kotmale, Sri Lanka, on September, 2015

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On the afternoon of Friday September 25, 2015, a landslide occurred in Lilisland, part of the Wedamulla Estate of Kotmale, Nuwara Eliya District, Sri Lanka; seven people were killed. Immediately after the disaster, the National Building Research Organization (NBRO) conducted a survey and produced the “Preliminary Land Survey Report on the Landslide Occurrence in Lilisland of Wedamulla Estate of Kotmale AGA Division, Nuwara Eliya District” (hereafter, the NBRO report). A Japan International Cooperation Agency (JICA) survey team performed a field survey after the landslide disaster in Koslanda, Badulla District, at the end of October 2014, and introduced a sediment disaster survey method that is now widely used in Japan and Sri Lanka. Also at this time, we (i.e., a JICA survey team) conducted a 2-day field survey on September 30 and October 1, 2015, for the purpose of elucidating the type of disaster and its underlying mechanism. In addition, we conducted an after-action review (AAR) on September 30 and October 1, 2015, and on December 19, 2016, and confirmed the situation at the time of the disaster. We compiled the results into a report for use in countermeasures against sediment disasters in Sri Lanka.

Key words: shallow slope failure, peak discharge of debris flow, velocity of debris flow

1. SUMMARY OF RAINFALL AND GEOLOGY AT THE DISASTER SITE

According to the nearest Department of Meteorology (DoM) rain gauge (10 km southeast of the disaster site, on top of Mt. Pidurutalagala) (Figure 1), the precipitation values on September 25, 2015, at 08 : 30, were as follows : daily precipitation of 33.0 mm and weekly precipitation of 76.5 mm. For September 26 at 08 : 30, the daily precipitation was 19.5 mm and the weekly precipitation was 91.5 mm. Additional information from the rain gauge of the tea estate, located in the same region, indicated that there had been 135 mm of precipitation on September 25.

Precambrian strata of granulite facies metamorphic rocks, classified as the Highland Complex (HC), underlie the Central Highland area, which includes the disaster site. Charnockite gneiss was confirmed at the disaster site. The charnockite gneiss observed in the Central Highlands often has ridge lines because of its fine and hard properties, and strong resistance to weathering; was observed at the disaster site in the form of a planar slope. Because they show similar strike and dip to the outcrops of the planar slope, the outcrops at the source, and along the course, of the debris flow imply that the dip structure developed
from foliation of the charnockite gneiss, as governed by the shape and direction of the aforementioned planar slope.

According to interviews with local inhabitants, large landslides apparently have not occurred previously in the disaster area.

2. RESULT OF FIELD SURVEY AND ESTIMATION OF THE RANGE OF DEBRIS FLOW TRAVEL

A summary of the 2-day field survey results follows. We used a Nikon COOLSHOT AS range finder (measurable distance of 4.5–550 m in a straight line) for distance measurements. We created a 1/5,000 topographic map from the Advanced Spaceborne Thermal Emission and Reflection Radiometer-Global Digital Elevation (ASTER-GDEM) model and calculated the basin area based on the field survey results, to be $\approx 30,000$ m$^2$.

Part A of the disaster site, in which the shallow slope failure occurred, has a length of 91 m and a width of 19 m, while the slope angle of part B was 21 degrees (Figure 2). After measuring the depth of the shallow slope failure, two steps of weathered rocks, with heights of $\approx 50$ cm, were piled up in cooperation with the local inhabitants and confirmed to have a total height of $\approx 1$ m (Figure 3).

The distance from the bottom of the shallow slope failure to part B in Figure 2 was 95 m (Figure 4). At B, the trace of the debris flow had a height and width of about 1.6 m; the flow initially took a shape similar to that of a valley or mountain stream and maintained it thereafter (Figure 5). It is believed that earth and sand gathered at the bottom of the shallow slope failure and moved to part B as a debris flow.

The slope angle of the lower part of B was 20 degrees. According to statements from local inhabitants, the conditions at the lower part of B did not change much before and after the disaster. Therefore, the earth and sand that became a debris flow in part B truncated thin surface soil on bare rock in the downstream region, and it was inferred that the debris flow moved downwards without much subsequent change in the quantity of material.

The slope angle at the upper stream near the houses damaged by the debris flow (part C in Figure 2) was 18 degrees. After confirming the trace of the debris flow at a region downstream from a damaged house, the depth of the sediment was determined to be $\approx 0.4$ m (Figure 6).

The affected house (marked in red in Figure 6), in the top row of houses, had been destroyed completely by the time of the field survey. The affected house (marked in blue in Figure 6) in the second row of houses was only partially destroyed. Between the affected houses in the top and second rows, the earth and sand, and part of an affected house, were deposited to a depth of $\approx 1.6$ m. According to interviews with inhabitants, four people died in the affected house in the top row of houses, while two people died in the affected house in the second row. Thus, it is considered that the debris flow moved downward, as follows.

(a) The debris flow collided with the house in the top row.
(b) After destroying the house, the debris flow damaged the house in the second row, and most of the earth and sand stopped at this point.
(c) A later flow (earth and sand flow) deposited downstream of the house in the second row to a thickness of approximately 0.4 m.

3. ESTIMATION OF SHALLOW SLOPE FAILURE : SIZE AND PEAK DISCHARGE OF THE DEBRIS FLOW

3.1 Estimation of the size of the shallow slope failure

According to the field measurements, the shallow slope failure had a width of 19 m and a length of 91 m. The thickness of the surface soil and weathered rock at the top part of the shallow slope failure was 1.0 m in extent, but the thickness of the sedimentation on the bedrock around the collapse area varied. Because grass partly covered the left side of the shallow slope failure area, it is thought that the area where grass was growing on the bedrock had collapsed in the past, although we do not know for certain when this occurred.

Assuming the height of the shallow slope failure to have been about half (0.5 m) the thickness of the surface soil and weathered rock, the total volume of the shallow slope failure was estimated at 864. 5 m$^3$, or approximately 870 m$^3$. 
Fig. 2 View of the entire affected area.

Fig. 3 Top part of shallow slope failure

Fig. 4 Area just beneath the shallow slope failure. Huge boulders (approximately 2 m in length) were deposited on the valley floor.

Fig. 5 Valley-like form of the debris flow trace
3.2 Estimation of the peak discharge and velocity of the debris flow

When a disaster of this type occurs in Japan, the peak discharge and velocity of the debris flow are often estimated. However, according to the NBRO, which has the primary responsibility for implementing countermeasures against sediment disasters, there is no record of NBRO officers having calculated/estimated these parameters. Therefore, we calculated these parameters to introduce the technique for calculating the peak discharge and velocity of a debris flow to the NBRO. Because the Manning roughness coefficient for Sri Lanka could not be obtained, we used the value for Japan.

The Manning formula states:

\[ v = \frac{1}{n} R^{\frac{2}{3}} T^{\frac{1}{2}} \]  

Where:

- \( v \) is the cross-sectional average velocity (m/s),
- \( n \) is the Manning roughness coefficient,
- \( R \) (\( = A/S \)) is the hydraulic radius (m),
- \( A \) is the cross-sectional area of flow (m\(^2\)),
- \( S \) is the wetted perimeter (m), and
- \( T \) is the slope of the hydraulic grade line.

From the field survey results, we divided the cross-sectional area into which the debris flow flowed into two cases; one with a rectangular section and one with a rectangular section + trapezoidal section; the reasons for doing this are as follows.

Case 1: The cross-sectional area of the debris flow was estimated as 1.6 m \( \times \) 1.6 m (depth \( \times \) height) from the result of measurements using the red and white poles at the disaster site (Figure 5). We defined this cross-sectional area as the rectangular section. We set the angle of the river bed to be 20.0 degrees based on actual measurements.

Gradient: 20.0 degrees (cf. Figure 2)
Maximum depth: 1.6 m (cf. Figure 5)
Width of the flow: 1.6 m (cf. Figure 5)
Cross sectional area of flow: 2.6 m\(^2\)

Case 2: When we considered the trace of the upper reach of the rectangular section, it was assumed that earth and sand flowed downward within a volume greater than that of the rectangular section (cf. Figure 5 A – 2). According to a photograph taken at the site, we estimated an actual debris flow width of 4.6 m within the upper reaches of the rectangular section, and took the height of the upper part of the rectangular section to be 1.0 m. Additionally, we defined the cross-sectional area of the debris flow as the rectangular section + the trapezoidal section.

Gradient: 20.0 degrees (cf. Figure 2)
Maximum depth: 2.6 m (cf. Figure 5)
Width of the flow: 4.6 m (cf. Figure 5)
Cross sectional area of flow: 5.7 m$^2$

We set the Manning roughness coefficient to 0.10, according to the “Manual of Technical Standards for Establishing Sabo Master Plan for Debris Flow and Driftwood.” This value of 0.10 is in general use.

According to the above, the peak discharge and velocity of the debris flow, calculated using the rectangular section case and the rectangular section + trapezoidal section case, are shown in Table 1.

The peak discharge of the debris flow was approximately 100 m$^3$/s, and the velocity of the debris flow was 4.0–4.8 m/s. These values are the same as the debris flow values used in Japan.

4. CORRESPONDENCE BETWEEN INTERVIEWS WITH INHABITANTS AND GOVERNMENT OFFICIALS BEFORE, DURING, AND AFTER THE DISASTER: RESULTS OF THE AFTER-ACTION REVIEW (AAR)

Interviews were conducted with nine people on September 30 and October 1, 2015, as part of the AAR, and on December 19, 2016, as a follow-up survey. The interviewees were as follows.
- four local inhabitants
- one estate manager and one factory mechanic
- one village officer (Grama Niladari; GN), Ramboda Division
- one Kotmale District secretary and one officer

Based on the results of the interviews, the observations made and actions taken were organized in chronological order, as shown in Table 2.

4.1 Date and number of disasters

When the results of the interviews were analyzed, it was ascertained that the time of the disaster outbreak was about 2:00 P.M. on September 25, 2015; there was only one disaster. Because the disaster occurred during working hours and most of the local adults had gone to the tea plantation to work as laborers, they avoided being victims of the disaster. However, many children who stayed at home were affected.

4.2 Disaster prevention system and official warning before the disaster

There is testimony that a crack appeared in the slope in the disaster area many years before the disaster. In addition, a crack formed in the wall of a house approximately 2 weeks before the disaster, and was investigated by the Divisional Secretariat (DS). However, the DS did not implement any special countermeasures, except to tell the inhabitant to pay attention to the situation.

No particular warning was given to residents of the affected area on the day of the disaster. Although heavy rainfall had begun, the inhabitants neither reported this to relevant organizations nor sought refuge, considering the event to be merely a bout of intense rain. Many inhabitants confirmed seeing danger signs, such as expanding cracks and abnormal water flow.

According to the interviews, some inhabitants did not care about these signs but others felt there was some danger. Nevertheless, even the inhabitants in the latter group said that they did not think that the slope would actually fail. For this reason (i.e., the presence of clear disaster risk signals that were noticed beforehand), it is particularly regrettable that casualties were not avoided.

It is necessary to enhance the disaster awareness of locals by creating a disaster management plan at the village level, which each organization is supposed to make, and by promoting reporting and evacuation before the occurrence of a disaster.

4.3 Sharing of disaster information

A report was made by local inhabitants to the GN just after the disaster, and initial information was transmitted from the GN to the DS and the police, and then from the DS to the district office of District Disaster Management Centre Unit (DDMCU) and NBRO, and finally from the district office of DDMCU to the Disaster Management Centre (DMC) and Tri Forces. Compared with the Koslanda disaster of October 2014, it is assumed that routes of communication were maintained such that smooth communication occurred (cf. Disaster Report of Koslanda:
https://www.jica.go.jp/srilanka/english/office/topics/150624.html).

The Kotmale disaster occurred in a plantation, and it was confirmed that a plantation manager called “estate manager” played an important role in sharing information with government offices in addition to the normal routes of communication. During the disaster,
the plantation manager was not within the estate, but he received information from the DS field officer and made arrangements for the provision of an ambulance. Furthermore, he shared the information he received with government officers immediately, thus contributing to a rapid first response.

4.4 Coordination among related organizations and logistical considerations

Correspondence between the district and division levels occurred during the disaster. A division-level disaster management plan was formulated by the Kotmale Division, and activities such as search and rescue, victim support, and adjustment of related organizations were implemented according to the plan.

The management of the tea plantation was also collaborative and provided support to locals, whose opinions of the activities of government officers and tea plantation managers were mostly favorable. However, some inhabitants pointed out that there were some other inhabitants who insisted with exaggeration their dissatisfaction in part.

Resettlement of the victims of the disaster was completed within 1 year, which confirms that the coordination abilities of the government office in charge of resettlement were high. In addition, according to the government officer, there were no particularly large problems pertaining to the logistics or resources of the disaster response. However, the disaster site is located in a remote area of the mountains, such that access to a hospital was not straightforward. This local infrastructure-related issue is problematic nationwide; although it cannot be resolved quickly, shows the necessity of considering the use of helicopters to transport injured persons from mountainous areas in the future.

5. Summary and Conclusions

The angles of the debris flow at the source area (21 degrees) and at the affected houses (18 degrees), were similar to that at the outbreak section (>15 degrees) of the debris flow. The reasons why the earth and sand did not reach the sedimentation or tractive sections are given below:

- The quantity of collapsed soil was extremely small.
- The house in the first row of houses served as a “Sabo dam,”; an erosion control dam, and restrained the earth and sand from outflowing.

The NBRO report also confirmed old landslides in two locations on the left side of the shallow slope failure area. Because shallow slope failure ruin (swamp line) like geographical features are also observable on Google Maps, it is thought that shallow slope failure-induced debris flows have occurred in the past.

According to the interviews with inhabitants, landslides had not occurred at the disaster site in the past, but it seems likely that small earth and sand outflows have occurred repeatedly, and that landslides may have occurred long ago. It is suggested that the debris flow moved downhill linearly, and did not open up in a lateral direction to any great extent because of the steepness of the riverbed. Because the surface sediment layer around the shallow slope failure area is thin, it is thought that the area could be at risk from debris flows after even a small rainfall event. In addition, we consider it important to check the situation (i.e., presence of cracks) concerning the bedrock around the shallow slope failure area in the future. Additionally, when a disaster occurs, it is advisable to conduct various investigations and collect disaster-related data to improve the accuracy of future disaster outbreak predictions.

In the response to this disaster, the NBRO involved cooperated and took action quickly and smoothly compared with the Koslanda landslide disaster, which occurred in a neighboring district in 2014 (i.e., approximately 1 year earlier). Nevertheless, it is regrettable that the local inhabitants did not attempt to seek refuge, particularly because warning signs, such as a shallow slope failure, were seen before disaster onset. The slope adjacent to the slope involved in the disaster has an almost identical situation, and it is expected that a shallow slope failure will occur there in the future. After the presently discussed disaster, local inhabitants took more interest in disaster prevention, but it is necessary to take further action to improve disaster prevention awareness in this area, and in neighboring areas.

During the disaster response, the NBRO conducted a preliminary land survey on the day following the disaster, identified dangerous areas with respect to the landslide, and advised related organizations accordingly. The initial correspondence that occurred immediately after the disaster is considered to have been sufficient. In this report, we investigated and compiled information about the disaster situation,
| Date               | Time              | Responder                        | Means of communication | Details                                                                 |
|-------------------|-------------------|----------------------------------|-------------------------|-------------------------------------------------------------------------|
| 10 years before the disaster |                  | Local inhabitants                |                         | Confirmation of a crack near the slope.                                 |
| September 9, 2015 | Around 12:00      | Local inhabitants, DS            |                         | Intense rain began in the Kotmale area.                                 |
| September 25, 2015| Around 14:00      | Local inhabitants                |                         | • Report of a flow of unusually muddy water.                           |
|                   |                   |                                  |                         | • An existing crack in the wall of a house was reported to have spread, but not to the government office because it was not deemed to be a sign of an impending disaster. |
|                   | Immediately after the disaster | Local inhabitants → GN | Telephone               | • Inhabitants reported to GN.                                          |
|                   | Around 14:00-14:30| • GN → DS, police               | Telephone               | • The GN reported to the DS and police.                                |
|                   |                   | • DS → GA, DDMCU, NBRO, and hospital | Telephone             | • The DS reported to the DDMCU and related organizations.            |
|                   |                   | • GA → DMC, Tri Forces          |                         | • The GA reported to the DMC and requested the dispatch of Tri Forces. |
|                   | Around 14:45-15:05| GN, DS, Police, Estate Manager  |                         | • Relevant people, such as the GN, DS staff, and the estate manager, arrived at the disaster site and began supporting the victims. |
|                   | Around 15:30      | Tri Forces CEB DDMCU             |                         | • The Tri Forces search and rescue team arrived at the site (engaged in activities until the 26th) |
| September 26, 2015|                  | NBRO                             |                         | • CEB staff arrived at the site and cut off the power supply.         |
|                   |                   |                                  |                         | • DDMCU staff arrived at the site and began to manage the support operations. |

DMC : Disaster Management Centre

DDMCU : District Disaster Management Centre Unit (under the DMC)

The DMC is an organization under the Ministry of Disaster Management that manages disaster responses in Sri Lanka.

It is similar to the Cabinet Office in charge of disaster management in Japan. Sri Lanka has 25 districts, and the DDMCU, under the DMC, was established for general management of disaster responses in all districts.

GA : Government Agent

DS : Divisional Secretariat

GN : Grama Niladari

An administrative office of the government established in 25 districts and operating as a District Secretariat. The Director General is also referred to as a government agent (GA). A total of 333 divisions have been established as a substructure of the District Secretariat, which is an administrative organization having jurisdiction over a division and called as Divisional Secretariat (DS). Approximately 14,000 GN divisions (meaning “village officer” in Sinhalese) exist as a substructure of Divisions. At the GN level, there are only one or two staff members, but this organization is in closest proximity to local inhabitants.

CEB : Ceylon Electricity Board : state electric power company

The CEB bears the duty to cut off the power supply in all or part of a disaster area to prevent electric shock accidents according to a request from a related organization. The CEB dispatches an emergency response team to disaster sites as necessary.
including the actions of local inhabitants before and afterwards. By referring to our disaster report, we hope that the NBRO will compile disaster survey data for Sri Lanka continuously and steadily in the future.

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