Survey Results of Aranayake Disaster
※ The results presented in this report may be revised based on further surveys.

1. Survey Purpose
Following the aerial survey on 22th May. 2016, we conducted field survey in order to analyze and check the further detailed situation. Regarding the aerial survey, see the following homepage of JICA Sri Lanka office.

2. Date and members of the survey
● First survey:
8th May. 2016 1:00pm – 4:00pm and 9th May. 2016 9:30am – 3:30pm
● Second survey:
21st May. 2016 12:00am – 4:00pm and 22nd May. 2016 10:00am – 12:30am
● Members of survey
Mr. Kenichi HANDA JICA expert/MLIT
JICA TCLMP, Chief Advisor, NBRO
Mr. Akira OHKAWARA Nippon Koei Co. Ltd. 【Second survey】
JICA TCLMP, in charge of Landslide (Design • Supervision)
Mr. Mitsuya OKAMURA JOCV/NITTOC Construction Co. Ltd.
LRRMD, NBRO
Dr. Masahito ISHIHARA JICA expert 【First survey】
JICA PIMOWFD, Chief Advisor, DoM
Mr. Ryo NAKANO NITTOC Construction Co. Ltd. 【First survey】
Mr. Akira SASAKI Earth Science System Co. Ltd. 【Second survey】

3. Situation of Disaster Occurrence
The results of interview with inhabitant who is 30 years old; man is below.
[Cf.Photograph-9]
He said,

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1 Technical Cooperation for Landslide Mitigation Project
2 National Building Research Organization
3 Japan Overseas Cooperation Volunteers
4 Landslide Research & Risk Management Division
5 Project for Improving Meteorological Observation, Weather Forecasting and Dissemination
6 Department of Meteorology
17th May, 5:18 pm, because I heard a sound like ‘Dawn: the sound that an airplane crashed’, I got out of house. A slope that I can see from my house already collapsed and drifted down, when I went out in around two minutes. The debris flew down to my house.

18th May, 0:20 am, the sediment began to flow once again at midnight. It seemed that water was deposited at stopping point of debris flow which flowed at 17:18. And the waters and soil seemed to flow out again.

According to the director of LRRMD, NBRO, there are information that the disaster occurred at about 4:30pm. It is necessary to confirm the details by conducting AAR and interview with inhabitants about the time when disaster occurred in future. According to the result of interview with inhabitant, it is estimated that the process of disaster occurrence in the evening of 17th May is as follows at this time.

1. Landslide/Collapse occurred in the upper slope in the evening.
2. The landslide / collapse moved down and flew out from to downstream nick line (the turning point of the slope degree) of the upper slope.
3. The debris became a debris flow and stopped once in the figure -1, "mountain stream part" and "around the exit of stream/valley."
4. In the midnight, natural dam made by debris flow collapsed due to the water which deposited in it, water and mud overflowed in the paddy of "the lower part."

4. Scale of Landslide
Grasp of the landslide affected area and estimation of soil movement were done based on the aerial photo taken from the helicopter survey on 22nd May. And result of LiDAR (Light Detection and Ranging) survey for terrain data and aerial photo before disaster (in December, 2015), was provided from the Survey Department of Sri Lanka, which was prepared by JICA’s Development Survey “Capacity Development Project for Creating Digital Elevation Model Enabling Disaster Resilience”. This terrain data was provided by DEM (Digital Elevation Model) format which excluded the surface coating (like vegetation and houses). On the other hand, result of the aerial photo analysis was developed by DSM (Digital Surface Model) format which is including the surface coating. Therefore, an estimation of soil movement was carried out only in the surface outflowed area (red frame, as mentioned in Figure 1). Normally the accuracy of aerial photo analysis is confirmed by using GPS or air marks. But in this survey, it was difficult to set air marks due to the emergency response. The bench marks for the model were set by any point taken from the photograph (such as intersection, house, tree etc.). And also the terrain correction for improvement of analysis accuracy was conducted to be consistent with actual conditions of deposition by the site survey. The result of analysis is summarized in the following.

All of the affected area from the main scarp to the end part of the landslide has a
maximum width of about 500 m and 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 [refer to Figure 1].

4-1. Upper Slope: Length 1,100m, Maximum width 500m [refer to Photo 1 - 5]
“Upper Slope” was subdivided and classified into “Near the Scrap”, “Outcrops Part” and “Lower Part of Outcrops”. The result of analysis, the main scrap was approximately 25m in depth (as referred to Cross-Section A-A’), and 150m in width. The amount of collapsing sediment was roughly estimated to be around 200,000 m³ at “Near the Scrap”.

The initial topography by the LiDAR survey, the slope angle was around 25 – 30 degrees. The collapsing sediments have been estimated to outflow while repeating the deposition and erosion because a steep slope at the outcrop part and a gentle slope were mixed in the “Upper Slope”. Also the deposition of sediment in about 1 - 5m was confirmed at the left side of the “Lower Part of Outcrops”. That still remains on the slope.

4-2. Stream Part: Length 500m, Maximum width 100m [refer to Photo 7 - 8]
“Stream Part” was subdivided and classified into “Narrow Part” and “Outlet Part”. The result of photo analysis, the deposition of collapsing sediments including boulders is estimated to be approximately 2 - 5 m at the “Narrow Part” (refer to Cross-Section C-C’). The deposition about 10m and maximum 5m of boulders was confirmed at the “Outlet Part” by site survey. The amount of deposition was estimated to be around 120,000 m³ in this part.

4-3. Lower Flat Area: Length 400m, Maximum width 200 ~ 350m [refer to Photo 11 - 12]
The result of the site survey, most mudflow including boulders has stopped at the “Outlet Part”. But when the disaster occurred, three days continuous rainfall was over 300mm. Fine textured soil has been outflowed and deposited in the flat area. The thickness of deposition was confirmed 0.5 ~ 1.5 m from the “Outlet Part” to the end point of the landslide (refer to Cross Section D-D’) by the result of photo analysis. The amount of deposition was estimated to be around 80,000 m³.
Cross-Section A-A’ Near the Scrap

Cross-Section B-B’ Deposition at the Lower Part of Outcrops

Cross-Section C-C’ Deposition at the Narrow Part

Cross Section D-D’ Deposition at the End point of Landslide
Figure 1 Landslide Overview (Left) and Height Change Estimation (Right)
5. Mechanism of the disaster occurrence

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

① The slope where landslide occurred is a huge slope which also having the height distance of about 600m, and about 2km in length from the top scarp of landslide to the mudflow deposition flat area down below.

② The slope direction is for north. That slope is consisted of hard base rock of granitic gneiss – muddy gneiss, and is as harmonic as the geographical feature of the shape of ridge continuous in the direction of east and west in surrounding area.

③ According to the hazard map (scale: 1/10,000) of NBRO, it shows the danger of slope classification which mainly considered by the gradients of geographical angle of slope. Danger classification is divided in four. The topmost bluff part in the slope is the most dangerous, the area from the upper slope to a stream part become the 2nd and the 3rd dangerous part, the part along the stream and the alluvial lower flat area down below become the 3rd and the 4th danger classification (the minimum danger). (refer to Figure. 2).

④ According to the latest news and interview from local residents, landslide occurred at the evening time around 16:30 - 17:30 of May 17. The sediment movements continuously occurred about 2km from the top of slope to a lower flat area. Firstly, the landslide occurred in the topmost steep slope, and the sediment become debris in the mountain stream part of the middle of the slope, then it reached to the lower flat area of the end, and have stopped moving.

⑤ The total rainfall for three days on May 15 to May 17 just before the landslide occurred was more than 300mm. 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 which poured under the ground. Also it is considered that those debris have flew out to the lower part with surface water in accordance with the geographical shape.

⑥ Some houses were dotted around the upper slope, and also crowded along a lower flat area like a colony. In the heavy rain situation on the day, in particular, since the first landslide area was far from the downward colony, residents were not able to afford to notice of landslide movement occurred in the upper part of the slope. Therefore, residents were involved in the debris which has moved, and damage was expanded.

⑦ According to the estimation at the site, the scale of the landslide occurred at first on the topmost is about 150m in width , about 100m in length , 15m in thickness. The amount of first landslide in upper slope and that of moving sediments are about 200,000 m³ estimated at most.

⑧ From the inside of base rock where is located directly under the top scarp of landslide, much quantity of groundwater is spreading continuously at the investigation time, and flowing down as surface water toward the lower part. That
is, a considerable quantity of groundwater is stored at the topmost slope in the crack portion of a base rock. Spreading of the stored groundwater is the direct cause of the topmost landslide occurrence. The landslide moved to lower part in accordance with the geographical feature form of a slope, and became debris flow with deleting a surface sediments on the way.

9) Deposition of big rock (maximum diameter of almost 5m) is restricted inside of upper slope and along the stream part. Only the fine fractions have reached at the lower part of flat area. The landslide and debris caused by first landslide about 2km in length occurred under the influence of a lot of surface water and groundwater due to the heavy rain.

10) Now, a lot of sediments are deposited not only inside the upper slope but along the stream part. Therefore, at the time of future when we have heavy rain, re-movement of the deposited sediments is worried by surface water and poured groundwater.

6. Suggestion about Emergent Measures
In response to this landslide disaster, our observations during this field survey led to the following recommendations:

- Non-Structural Mitigation Measures
  - It is necessary to make the evacuation plan of inhabitants at the time of future heavy rain. The same plan about surrounding area is also necessary.
  - For inhabitants and neighboring inhabitants, it is necessary to educate about further disaster prevention.
  - Improvement of the hazard map is necessary. Specifically, it is needed to improve the method to estimate the affected area in reference to Japanese yellow zone setting method.

- Structural Mitigation Measures
  - The setting of the emergency sand guard structures is necessary to keep this area from debris flow caused by future heavy rain. (we think that a simple countermeasure which made by gabion may be appropriate)
  - Some houses, school and village which did not suffer from disaster remains near the collapse. The temporary restoration (including the lifeline restoration such as electric wires and roads to go to there) is needed, if there is no plan to move/shift these houses to safe place. In order to do that, a restoration plan of this area is necessary.
Figure 2  Landslide Hazard Zonation Map of NBRO and disaster areas (From NBRO homepage)
<table>
<thead>
<tr>
<th>Photo-1</th>
<th>The most upper part of collapse&lt;br&gt;It was estimated that the front gray rock piece of this photo was fall from the center of collapse and deposited.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Photo-2</td>
<td>The running water on the collapse&lt;br&gt;Although it was hard to look with the photograph, water fell down the central part.</td>
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<tr>
<td>Photo-3</td>
<td>Slope on the left side of collapse&lt;br&gt;A part of the light brown was left on the right side, and it was expected to collapse in future.</td>
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<tr>
<td>Photo-4</td>
<td>The situation of the slope lower from naked rock&lt;br&gt;Slope of the B side of the B-B' section of figure -1. We can understand that the collapse mass deposited lower part.</td>
</tr>
<tr>
<td>Photo-5</td>
<td>Remained trees near the naked rock part I could understand that the sedimentation soil was thin when I confirmed a left tree near naked rock part by viewing.</td>
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<tr>
<td>Photo-6</td>
<td>Approximately 150m upper of point of the C-C' section figure -1&lt;br&gt;At this part, the debris from the left and right valley joined.</td>
</tr>
</tbody>
</table>
Photo-7  The huge rock which remains in stream part
Although the outbreak point of this huge rock was unidentified, it was estimated that it moved in this disaster.

Photo-8  The end part of deposited debris flow
We heard from the inhabitant of photo-9 the white wall house is his.

Photo-9  Situation of interview to inhabitant
Mr. Okamura: JOCV (the center of photo), interviewed in Singhalese and confirmed the situation at the time of the disaster.

Photo-10  The Slope to see from photo-8 and 9.
We cannot confirm "Near the scrap" including collapse from this place.

Photo-11  Affected house on "Lower flat face" The debris deposited around 1.5m here.

Photo-12  The situation of "Lower flat face" The central white house is facilities for prayers of neighboring temples. The debris deposited around 0.5m here.