An Investigation on One of the Rainfall-Induced Landslides in Malaysia

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ABSTRACT

Rainfall-induced landslides are very common in Malaysia especially during rainy seasons. Some of these landslides have resulted in not only extensive damage to properties but also loss of lives. An investigation has been carried out on one of the major landslides which occurred in Hulu Klang, known to be a landslide-prone area. The study involved: (i) determination of mode and mechanism of failure based on information from site investigation, field data collections and eyewitness accounts, (ii) back analyses and (iii) identification of contributing factors. The failure can be classified as a deep-seated failure caused by existence of high pore-water pressure within the slope. The landslide may be attributed to a combination of factors such as: existence of loose soil from earth dumping on the slope which took place during the development of the area, prolonged rainfall during the months of October and November, widening of existing cracks and opening of new tension cracks due to prolonged creep and lastly damage of water pipe due to soil creep.

KEYWORDS: Landslide; pore-pressure; back-analysis; tension cracks; soil creep.

INTRODUCTION

In the early morning of the 6th December 2008, a landslide occurred at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor, Malaysia (Figure 1) (Slope Engineering Branch of the Public Works Department Malaysia, 2008). The landslide took place at approximately 3.30 a.m., measuring 109m in width at the crest, 120m in length, 15m in depth and the angle of the scarp at the crown was approximately 45^o to 50^o. It was estimated that 101,500 cubic meters of earth had translated and the maximum run out distance of the failure debris was measured at approximately 210m from the toe of the slope (see the cross-section in Figure 2).

The landslide debris completely blocked Jalan Bukit Antarabangsa, the only road access for some 5000 residents living in the area. Fourteen (14) bungalow houses were destroyed and five (5) fatalities and injury to fourteen (14) persons were reported.

A special committee was formed to carry out the landslide investigation works. The committee consisted of various agencies and was led by the Slope Engineering Branch of the Public Works Department (PWD), Malaysia. The objectives of this investigation were to identify the probable cause(s) of the landslide and its contributing factors, to explain the mode and mechanism of the landslide. The investigation was also aimed at providing information that would assist in the short and long term remedial measures and determining immediate recommendations for areas of high risk.

Figure 1: Overall View of the Bukit Antarabangsa Landslide

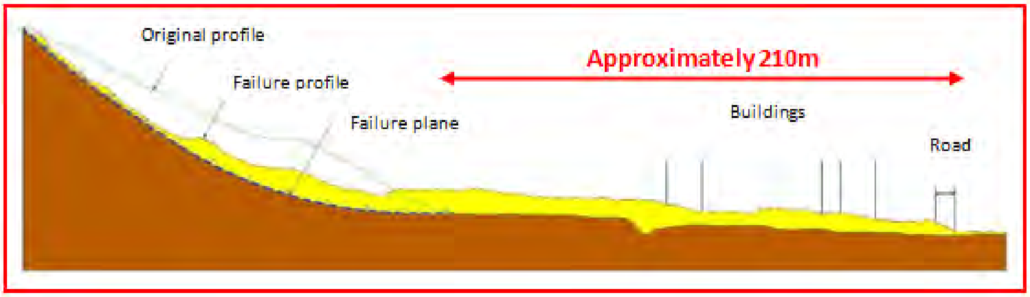

Figure 2: Cross-section showing the Estimated Failure Plane and Failure Run-out Distance of 210 m

DETAILED INVESTIGATION PLAN

In order to achieve the objectives of the investigation, the following major components of the works were undertaken;

a) Establishing the terrain model
b) Establishing the geotechnical model
c) Establishing the mode and mechanism of failure from desk study, eyewitness accounts, ground survey and site investigations
d) Conducting back analyses to support/ identify the mode and mechanism of failure by identifying pore water pressure conditions at failure.
e) Concluding on the factors contributing to the failure.

Figure 3 shows the investigation plan and flow chart of the investigation works undertaken.

Desk Study

Aerial Photography: A series of aerial photographs from year 1966 to 2008 were provided and interpreted by the Department of Surveying and Mapping Malaysia (JUPEM) which revealed a history of the progressive development that had taken place at the landslide area and its vicinity (Figure 4). These aerial photographs were also interpreted by Minerals and Geoscience Department of Malaysia (JMG). Aerial photographs from 1966 show the existence of hill ridges, Sungai Seriang and its tributaries at the failure area (see Figure 5). By 1989, the ridge areas had undergone extensive development. The area that was once the river bank of Sungai Seriang formed part of Taman Bukit Mewah and the original river course was replaced by concrete drains and a large monsoon drain.

Geology of the Failure Area: The Geological Map of Selangor (Sheet 94) Kuala Lumpur (1976) published by the Geological Survey Department of Malaysia shows that the landslide area is underlain by granite rock of Triassic age. This granite is also known as Kuala Lumpur Granite which is part of the Main Range Granite that has intruded into folded and regionally metamorphosed clastic and calcareous Paleozoic rocks. In general, the residual soils in this area are made up of residual granite at various stages of decomposition overlying the parent rock mass. Highly weathered and jointed granitic bedrock underlies the subsoil profile of the area.(Ali & Harianto, 2004; Ali & Huat, 2006)

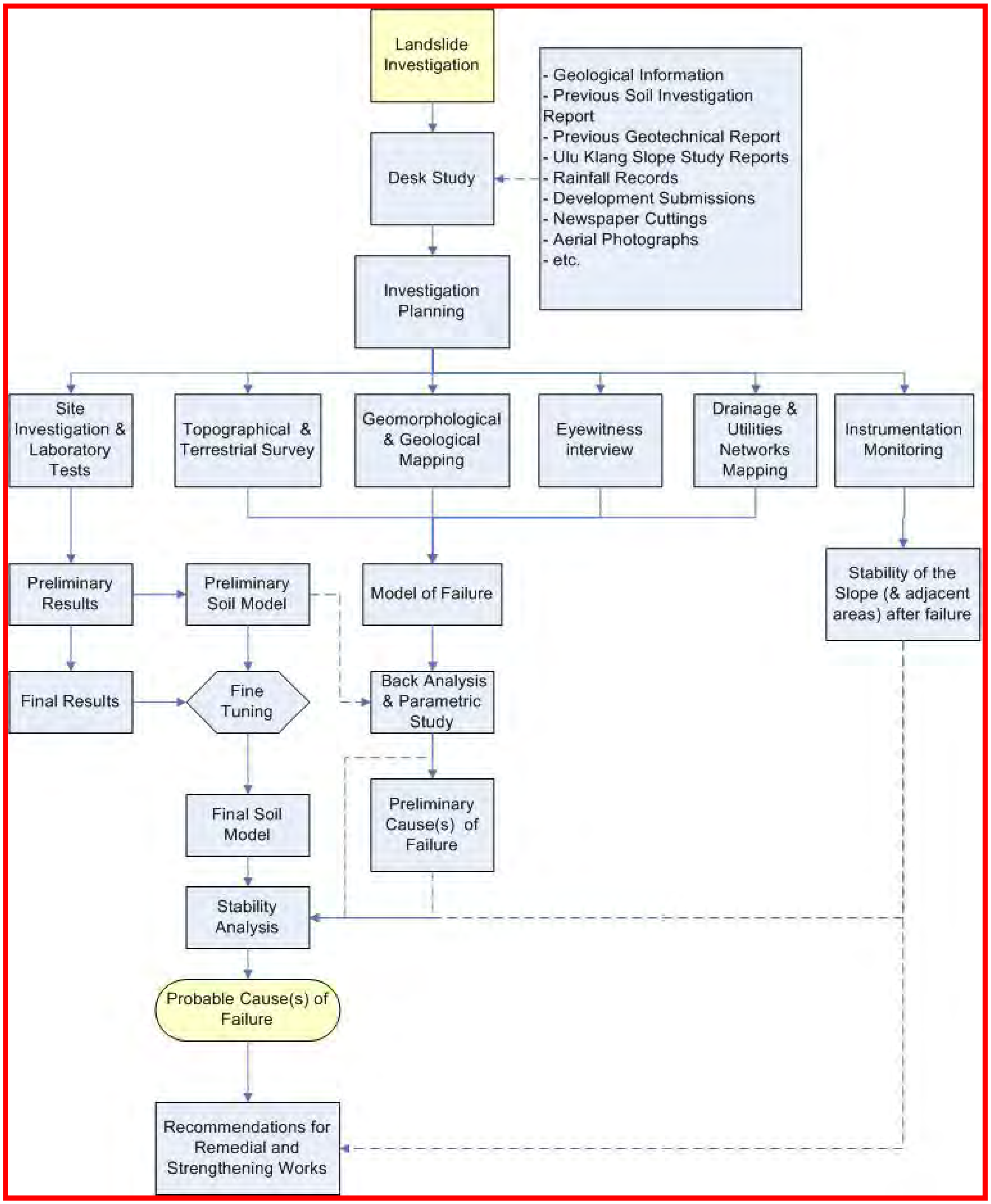

Figure 3: Investigation Plan and Flow Chart of the Investigation Works Undertaken

Rainfall Records: Rainfall records from 1st November 2008 to 7th December 2008 were collected from four (4) nearest meteorological stations to the landslide site. They ranged approximately 6km to 25km from the site. The rainfall station closest to the failure site was the Bukit Antarabangsa Station. However, the station was established in 2003; hence the only available monthly rainfall records were obtained for year 2003 to 2008 (Figure 6). It is clearly shown that the monthly rainfall for the month of October and November in 2008 recorded the highest rainfall since 2003. The monthly rainfalls for October and November 2008 are 594mm and 592mm respectively totaling 1186mm which is equivalent to 45% of the yearly average rainfall in Bukit Antarabangsa for the five (5) year period of 2003 to 2008.

Based on the frequency distribution of annual maximum rainfalls for various duration the results of the average recurrence interval of return period are shown in Table 1.

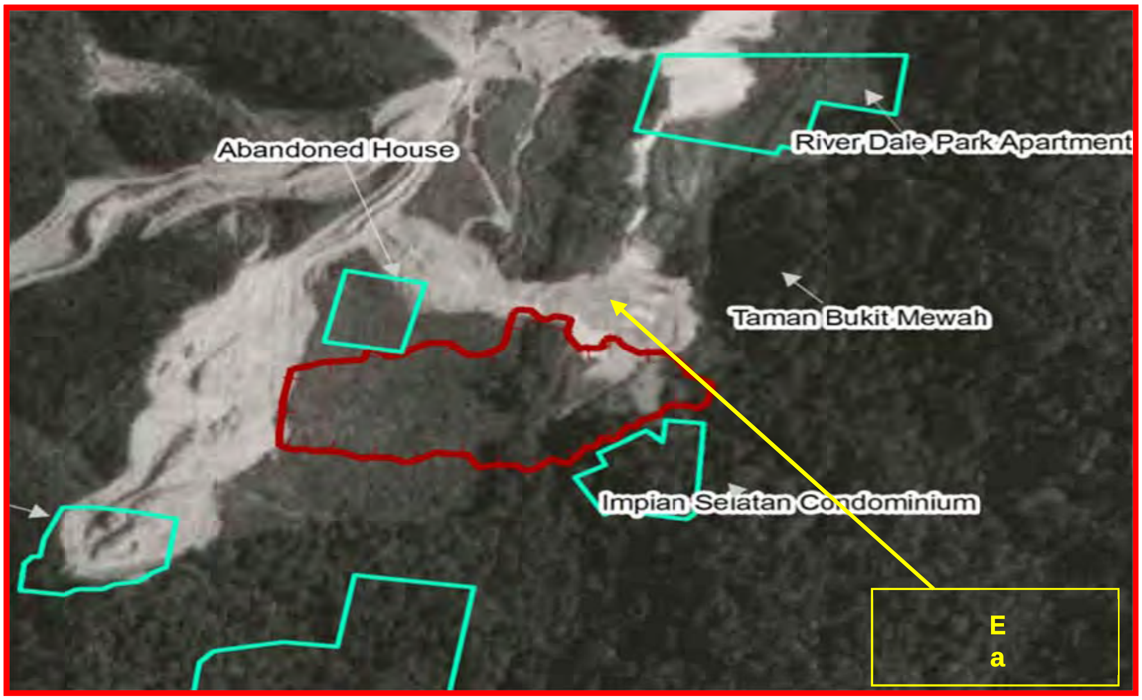

Figure 4: Aerial photograph (1975 by Department of Surveying and Mapping Malaysia) showing evidence of Earth Dumping

Table 1: Average Return Period for the Rainfall Depth recorded prior to failure at Bukit Antarabangsa

Rainfall Duration (days)	Rainfall Depth	Average Recurrence Interval (ARI)*(years)
1 day	86	2
3 days	182	4
4 days	224	8
5 days	266	15
6 days	305	20
7 days	336	20

14 days	472	20
30 days	494	3

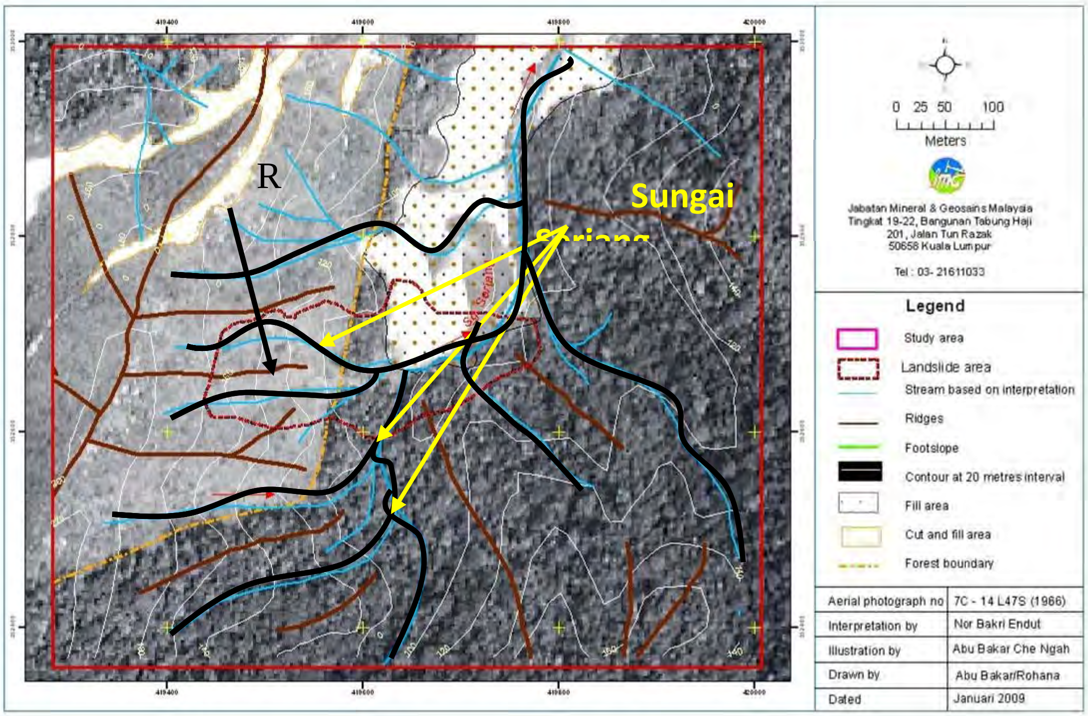

Figure 5: Aerial photograph (1966 by Minerals and Geoscience Department) shows the River, Sungai Seriang and its Tributaries

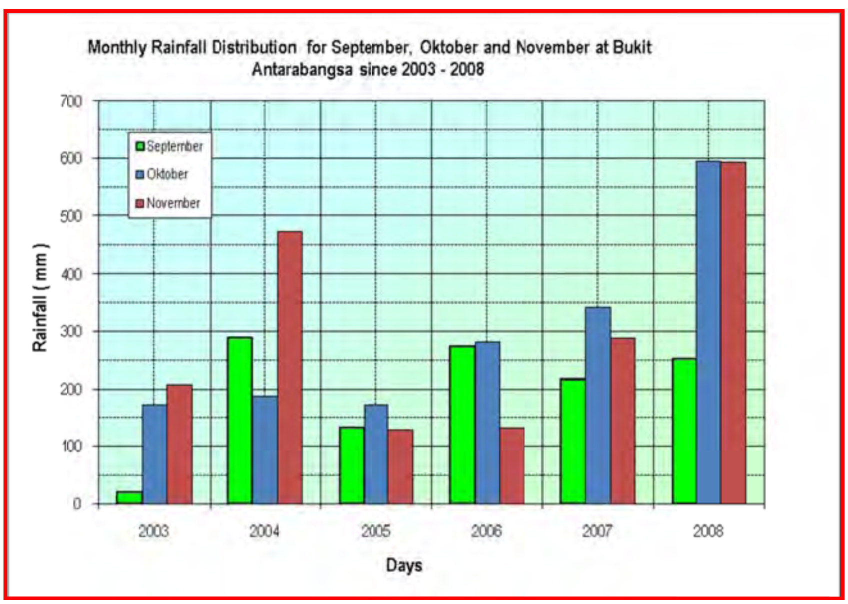

Figure 6: Monthly rainfall records for the September, October and November 2008 at Bukit Antarabangsa Station

Observations before Landslide: Before the landslide took place, some general observations were noted on the topography of Taman Bukit Mewah. The topographical information was collected using LiDAR (Light Detection and Ranging) while some field observations were carried out (by Public Works Department) in September 2007. The field observation revealed that the soil at the landslide location was creeping and showing signs of instability i.e. trees leaning, ground movement, arcuate cracking on the road pavement and etc.

Eyewitness Account: Relevant eyewitnesses were called forward for an interview with the investigations team. This was carried out to obtain information with regards to the history of the site and also accounts of the events that led to the landslide.

SITE INVESTIGATION

A detailed site investigation was undertaken to form the basis of this investigation. The site investigation consisted of surface and subsurface investigations. The surface investigation consisted of:

a) Topographical & Terrestrial LiDAR survey (TLS)
b) Geomorphological and Geological mapping
c) Surface infiltration test and soil sampling

Topographical & Terrestrial LiDAR Survey (TLS)

Detailed topographical survey is important in determining the terrain model of the failed area. Terrestrial LiDAR survey (TLS) was carried out to map the failure zone. Figure 7 shows a 3D terrain model produced from TLS.

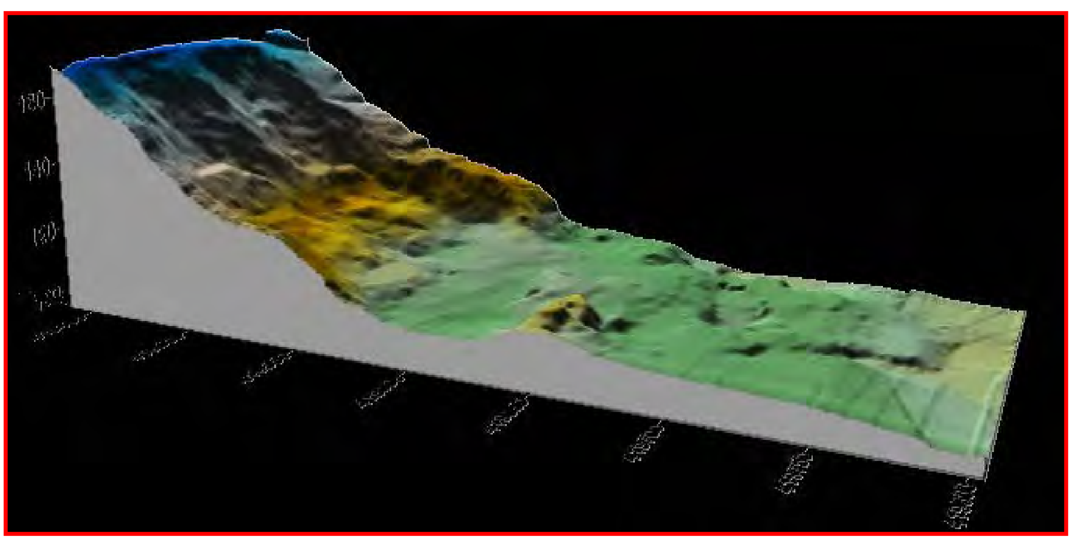

Figure 7: 3D Terrain Model produced from Terrestrial LiDAR Survey (TLS)

Geomorphological and Geological Mapping

A team of geologists and geotechnical engineers carried out the geological and geomorphological mapping works. Among the observations included rows of abandoned houses very near to the failure area (see Figure 8). The failure also exposed a damaged water pipe of 215mm in diameter and sewerage pipes. These exposed pipes were located underneath the abandoned houses.

Figure 8: Failure area and location of the abandoned houses

Surface Infiltration Tests, Instrumentation and Soil Sampling

Surface Infiltration Test: Six (6) locations were selected where the surface infiltration tests were carried out to measure the in-situ infiltration capacity of the soil with two (2) tests assigned at each location. The double ring method was adopted to perform the tests (Ali et al, 2005; Huat, et al , 2006). In general, the infiltration capacity obtained for these locations ranged from 1x10-5m/s to 5x10-5m/s.

Subsurface Investigation: A total of twenty five (25) borehole investigations were carried out at the landslide area and its surroundings. To avoid further disturbance to the slope, foam drilling method was used in most of the boreholes to retrieve appropriate samples for the laboratory testing, as wash boring method was not advisable. Most boreholes were terminated after encountering five (5) SPT-N values of 50. Undisturbed soil samples collected by means of the 75mm diameter thin-walled samplers were also proposed for various laboratory tests. Among the laboratory tests conducted on the samples were Soil Index Properties Tests, Infiltration/

Permeability Tests, Consolidated Isotropic Undrained Triaxial (CIU), Compaction Test and Unconfined Compression Test (UCT) on the rock samples obtained. Instrumentation monitoring was carried at the failure and surrounding areas. Ground movement monitoring, i.e., ground markers, prism movement markers, and inclinometers, were assigned to areas adjacent to the failure scar. Piezometers were also installed to monitor the ground water level of the hill slope. Continuous samplings were also carried at some borehole locations for soil material logging (cut or fill material) in the laboratory. Based on the continuous sampling, it can be clearly seen that the top soil at the crest of the failed slope area consisted of loose fill, decayed wood, construction debris, etc.

Groundwater level was recorded every day from the boreholes during the progress of SI works. Upon completion of the SI, monitoring was done twice weekly for the next one (1) month and after that once weekly. Upon the installation of the piezometer, it was observed that the groundwater dropped 1m to 3m below its highest recorded level (recorded at the toe approximately 0.54 meter below ground level), and ever since, has stabilized. This entire motion took two (2) to three (3) weeks to reach its stable state.

Based on the subsurface investigation report and the borehole investigation, the subsoil profile of the site can be summarized as tabulated in Tables 2 and 3:

Table 2: Subsoil Profile (Within the Failure Scar)

Layer	Material Type	Depth	Remarks
Layer 1	SILT	0 to 13.5m	Average SPT 'N' = 9
Hard Layer	Sandy GRAVEL	13.5m to 17m	SPT 'N' >50
Bedrock	Granite	17m onwards	Average RQD = 20-100%

(RQD = Rock Quality Designation)

Table 3: Subsoil profile (left hand side-see Figure 1) and (right hand side-see Figure 1) of failure area.

Layer	Material Type	Depth	Remarks
Layer 1	Stiff sandy SILT	0 to 12m	Average SPT 'N' = 12
Hard Layer	Sandy GRAVEL	12m to 52.69m	SPT 'N' >50
Bedrock	Granite	52.69m onwards	Average RQD = 22-90%

(RQD = Rock Quality Designation)

A geophysical investigation was conducted 3 days after the failure. The investigation at the site involves the Resistivity Test and Seismic Refractory Test. These tests were conducted to determine the stratigraphy of the ground, ground water level and the soil saturation. The Minerals and Geoscience Department Malaysia's Report reveals the presence of highly weathered, fractured and saturated granitic bedrock ranging between 5 to 45m. This agrees well with the continuous sampling results and the borehole investigation that showed rock coring with average RQD of 50%. The investigation too revealed that at the crest of the failure area, some 10m thick fill material was detected. This result can be supported by rechecking the SPT-N values obtained based on boreholes located on the left and right hand side (see Figure 1) in between the landslide scar. Up to the depth of 15m, two (2) boreholes display variation of layers (silt, sand and clay) with SPT-N 0 to 10. Some resistivity lines detected pockets of saturated sandy material towards the right side (see Figure 1) of the failure scar.

MODE AND MECHANISM OF FAILURE

Seismic records obtained from Malaysian Meteorological Department show that there was no sign of earthquake motion on the day of the landslide, i.e., 6th December 2008, and also the month before. This eliminates the probable cause of failure due to earthquake.

From the eyewitness account, the affected bungalow houses were described to have been "floating up and down" when they were swept by the failure debris. This clearly indicates that the debris was "very fluid" in nature, and the landslide slip plane must have been deep, well below the founding level of some of the houses. The debris traveling distance of approximately 214m also confirms that the debris was "fluid-like".

The water pipe exposed at the failure scar near the abandoned houses (Figure 9) was reported to be an active water pipe (confirmed by SYABAS (a private water supply provider for Selangor State) personnel during the eyewitness interview). Rapid water flow in the drain along Jalan Wangsa 11 (the road at the crest portion of the failure) was reported by one of the eyewitnesses, around 1.39 a.m. on 6th December 2008 even though no rain was recorded over several days before the failure. SYABAS was informed and the immediate action carried out was to cut off the water supply to the area (by shutting off the main valve at the service reservoir) at approximately 2.30a.m. on the same day prior to the landslide. The SYABAS technician mentioned that a water source was found flowing from the direction of the abandoned houses (at the mid level of the failed slope) towards the roadside drains in Jalan Wangsa 11. In the midst of preparation to go into the area for repair works was when the landslide occurred.

From the mapping works carried out and the aerial photographs taken before and after failure, Jalan Bukit Antarabangsa (at the toe) was found to have heaved, and a few bungalows were displaced away from their original positions. The slide was deep-seated, where the sliding plane went below the road and the founding level of the first row of the bungalows (see Figures 9 and 10).

Figure 9: The Main Access Road, Jalan Bukit Antarabangsa, Heaved up more than 1m above its Original level

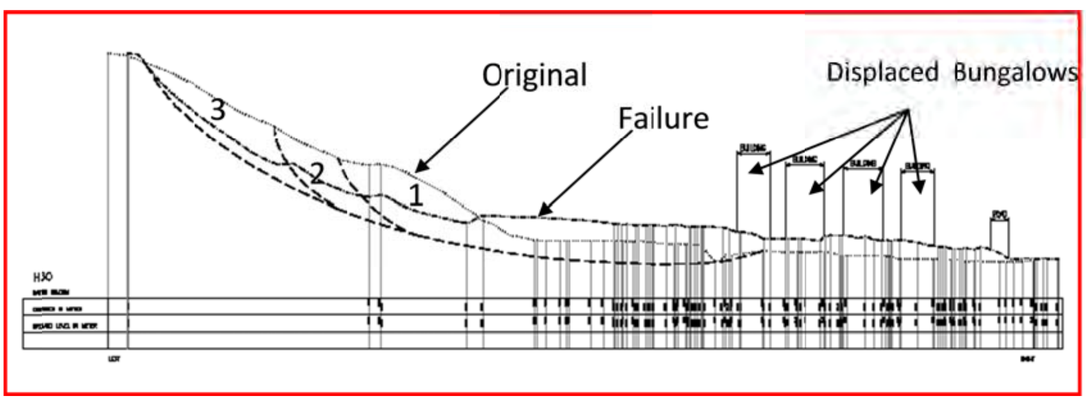

Figure 10: Cross Section Extracted from TLS and LIDAR showing the 3 (three) Slumps

The cross-sections extracted from TLS indicate that at least three (3) slumps were involved in the landslide (see Figure 10). It is believed that the lower berm of the slope gave way first followed by the second and third slumps above due to over steepening. This mechanism of failure concurs with some eyewitness accounts of three (3) loud crashing sounds during the landslide event within a space of 3 to 5 minutes. Furthermore, based on the eyewitnesses' accounts, the first loud crash resulted in the displacement of the bungalow houses (originally along Jalan Bukit Antarabangsa) to the main access road itself (bungalows were found 'sitting' on the main access road i.e. Jalan Bukit Antarabangsa). The second and third crashes (the second and third slumps) resulted in further movement and damage to the houses.

The ratio of the failure depth (approximately 15m) and the slope length (120m) was found to be greater than 0.1, thus the failure can be classified as deep-seated. Such a failure is usually governed by ground water and/or high pore water pressure within the slope (Othman, 1989; Huat et al, 2008; Low, 2011).

BACK ANALYSIS TO SIMULATE FAILURE

Geotechnical Model

From the boreholes investigations, it was found that the soils were believed to be dumped/spoiled earth without proper compaction. To reflect the non-engineered fill with loose lenses, lower shear strength parameters were adopted in the slope stability analysis i.e. within the range of c' = 2 to 4 kPa and φ' = 25 ^{o} to 28 ^{o}.

Failure Plane

The estimation of the failure plane was based on the findings of the geomorphological mapping works and cross section extracted from TLS works. This is shown in Figure 10. The three (3) slumps formed were responsible for the three (3) loud crashing sounds heard by the eyewitnesses during the landslide event. The extent of the first slump (at the toe/ base) was based on the findings during the geomorphological mapping works after the incident whereby the main road (Jalan Bukit Antarabangsa) was found to have heaved up.

Stability Analysis

Three (3) cross-sections were simulated in the stability analysis using SLOPE/W (2007) computer program adopting Morgenstern-Price's method, satisfying both the force and moment requirements. The three (3) cross-sections studied are within the landslide area, i.e., center of the landslide, Sections 1-1 and 2-2 (right and left side of the failure-see Figure 11).

Figure 11: Location of the Cross-Sections in the Analyses

The findings during the geomorphological mapping point out that the main road (Jalan Bukit Antarabangsa) heaved due to high pore water pressures in the slope. Based on eyewitness accounts, the first loud crashing sound displaced the bungalows to the middle of Jalan Bukit Antarabangsa. This proves that the first crashing sound indicated the failure of first slump at the slope toe. Therefore, in this stimulated analyses based on pore pressure ratio (Ru), the failure geometry of the surface slip that had taken place would be located at the toe of the slope (first slump).

Various pore water pressure ratios (r_u) were applied in the analyses to obtain the Factor of Safety (FOS) at the toe of the slope (first slump). From the analysis, it can be concluded that the Ru value at failure is likely to range from 0.20 to 0.25 (see Figure 12). Hence, high pore water pressure is believed to have developed at the toe which triggered the initial deep-seated slide (the first slump). Subsequently, this over steepened the slopes above, causing the rest of the two slumps to slide down within minutes after the first slide.

There are several causal factors contributing to the landslide. They are:

a) Soil creep due to non-engineered fill on the slope developed tension cracks over the area.
b) The soil creep over the years may have damaged the active water pipe along the abandoned houses and leaked the pipe. The leaks contributed to continuous soil saturation at the lower slope and this in turn, accelerated creep.
c) Loose/non-compacted "dumped earth" with high void ratio placed in the natural valley is high in permeability.
d) Prolonged rainfall during the month of October and November resulted in soil saturation, rise in ground water table and increases the rate of creep.
e) Increased soil creep further damaged the drainage facilities and widened the existing cracks and opened up new tension cracks.

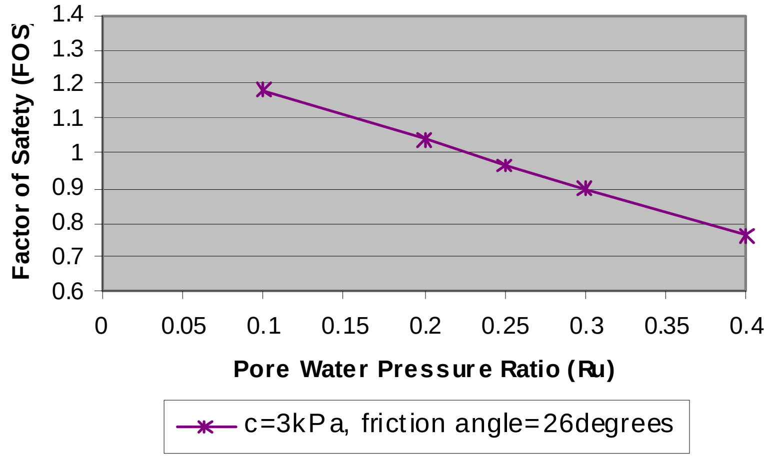

Figure 12: Factor of Safety (FOS) versus Pore Water Pressure Ratios

CONCLUSIONS

The landslide that took place on 6th December 2008 at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, and Selangor can be classified as a deep-seated failure. This kind of failure is caused by high pore water pressure within the slope.

From the failure assessment, it is concluded that the landslide can been attributed to a combination of the following factors:-

a) Loose soil from earth dumping on the slope which took place during the development of the area.
b) Prolonged rainfall during the months of October and November.
c) Prolonged soil creep which widened existing cracks and opened up new tension cracks.
d) Heavily leaked active water pipe along abandoned houses due to soil creep.

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