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AHLI MAJLIS MESYUARAT KERAJAAN NEGERI (EXCO) SELANGOR
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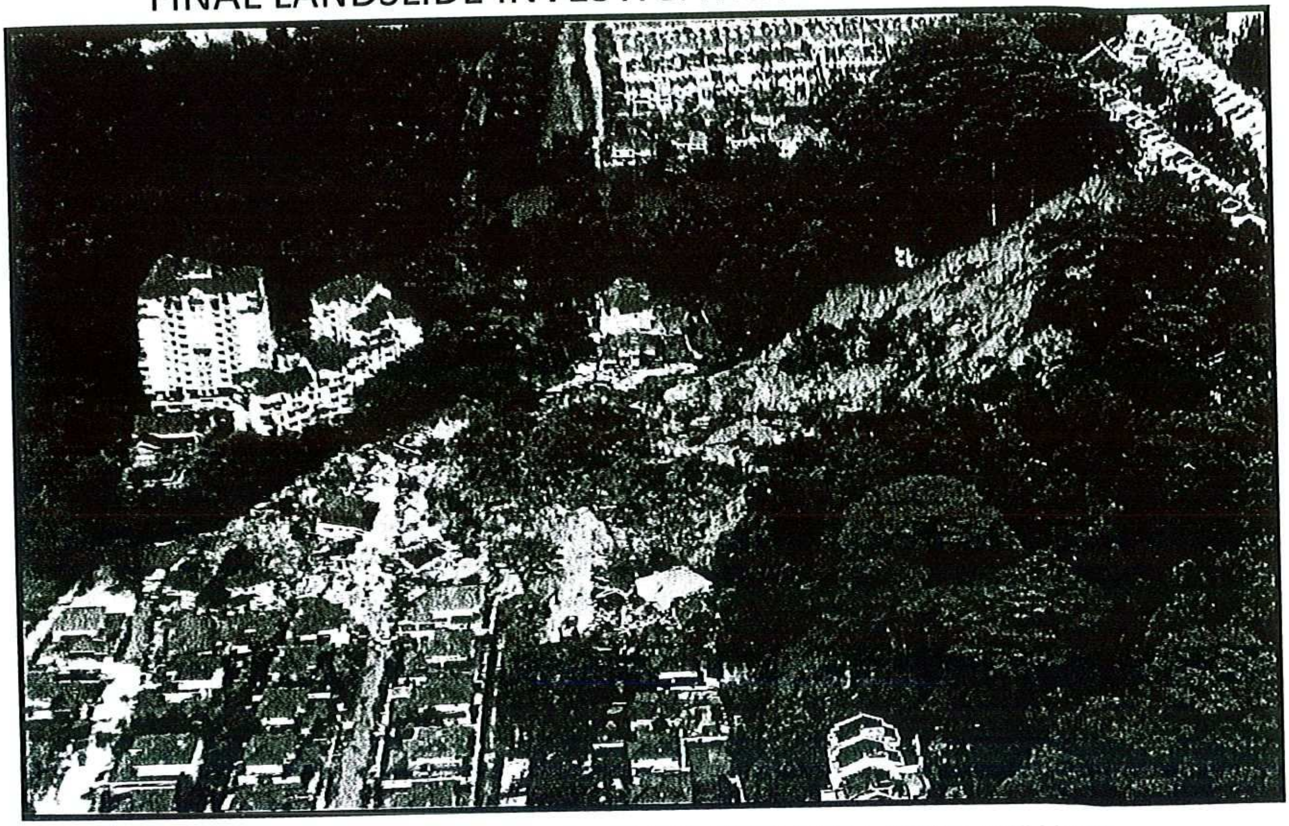
GOVERNMENT OF MALAYSIA

FINAL LANDSLIDE INVESTIGATION REPORT



INVESTIGATION OF SLOPE FAILURE AT TAMAN BUKIT MEWAH,

BUKIT ANTARABANGSA, HULU KLANG, SELANGOR

6 DECEMBER 2008

Volume I: Main Report

CAWANGAN KEJURUTERAAN CERUN
JABATAN KERJA RAYA MALAYSIA

Executive Summary

On 6th December 2008, a landslide was reported at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor. 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 of the crown ranges from 45° to 50°. 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.

The landslide debris completely blocked Jalan Bukit Antarabangsa, the only road access to some other 5000 residents. Fourteen (14) bungalow houses were destroyed by the failure debris. The landslide also resulted in five (5) fatalities and injury to fourteen (14) others.

A special committee was formed to carry out the landslide investigation works. The committee consisted of various agencies and was led by Cawangan Kejuruteraan Cerun JKR (CKC). This final report outlines the findings based on available data/document up to the stage of the report writing.

A total number of twenty-one (21) eyewitnesses were called for an interview with CKC-JKR. The interviews were carried out to obtain information with regards to the history of the site as well as accounts of the events leading to the landslide.

Detailed site investigation has been undertaken to form the basis of this investigation. The surface investigation consists of topographical and terrestrial LiDAR survey (TLS), aerial photograph survey, geomorphological and geological mapping and test pits, surface infiltration tests and soil samplings. Meanwhile, the subsurface investigations consisted of boreholes, instrumentation monitoring (piezometer and inclinometer) and geophysical investigation (by JMG).

The cross sections extracted from topographical and terrestrial LiDAR survey (TLS) confirmed that at least three (3) slumps were involved in the landslide. It is believed that the lower berm of the slope gave way first, followed by second and third slumps above it due to over steepening of the slopes. This mechanism of failure concurs with a few eyewitness accounts whereby three (3) loud crashing sounds were heard during the landslide event within a space of 3 to 5 minutes.

Based on the investigation undertaken, the landslide can be classified as a deep seated slide. Deep seated slides are generally caused by high pore water pressure.

From the investigations, the landslide is believed to have been contributed by 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) Poorly maintained/ damaged drainage system on the failed slope and its surrounding.

c) Prolonged rainfall during the months of October and November.

d) Prolonged soil creep that widened existing cracks and opened new tension cracks.

e) Heavy leakage of an active water pipe along abandoned houses due to soil creep.

From the above, the most probable triggering factor of the landslide is due to water leakage from the active water pipe along the abandoned houses that caused a build-up of high pore water pressure within the slope.

Immediate recommendations to prevent a reoccurrence of the landslide in Bukit Antarabangsa based on the final investigation works are as follows:

a) Efforts must be made to identify areas with similar non-compacted filled/dumped ground.

b) Repair and upgrade damaged and undersized drains within the vicinity of Bukit Antarabangsa.

c) Installing subsoil drains at areas where water seepage and high ground water table are located.

d) Undertaking instrumentation monitoring as early warning system at high-risk areas.

e) Undertaking detailed inspection and assessment of slopes with signs of distress. Areas with prolonged soil creep must be regularly inspected and preventive works must be immediately undertaken.

f) All water pipe adjacent to slopes shall be exposed.

g) All water and sewer utilities on slopes shall be inspected periodically for leakage and damage.

h) All hillside development shall follow strictly to the development guidelines by the local authority.

INVESTIGATION OF SLOPE FAILURE AT TAMAN BUKIT MEWAH, BUKIT ANTARABANGSA, HULU KELANG, SELANGOR

Final Landslide Investigation Report

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INVESTIGATION OF SLOPE FAILURE AT TAMAN BUKIT MEWAH, BUKIT ANTARABANGSA, HULU KELANG, SELANGOR

Final Landslide Investigation Report

1.0 INTRODUCTION

On 6th December 2008, a landslide was reported at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor (see **Figure 1**). 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 of the crown ranges from 45° to 50°. 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 to some other 5000 residents. Fourteen (14) bungalow houses were destroyed by the failure debris. The landslide also resulted in five (5) fatalities and injury to fourteen (14) others.

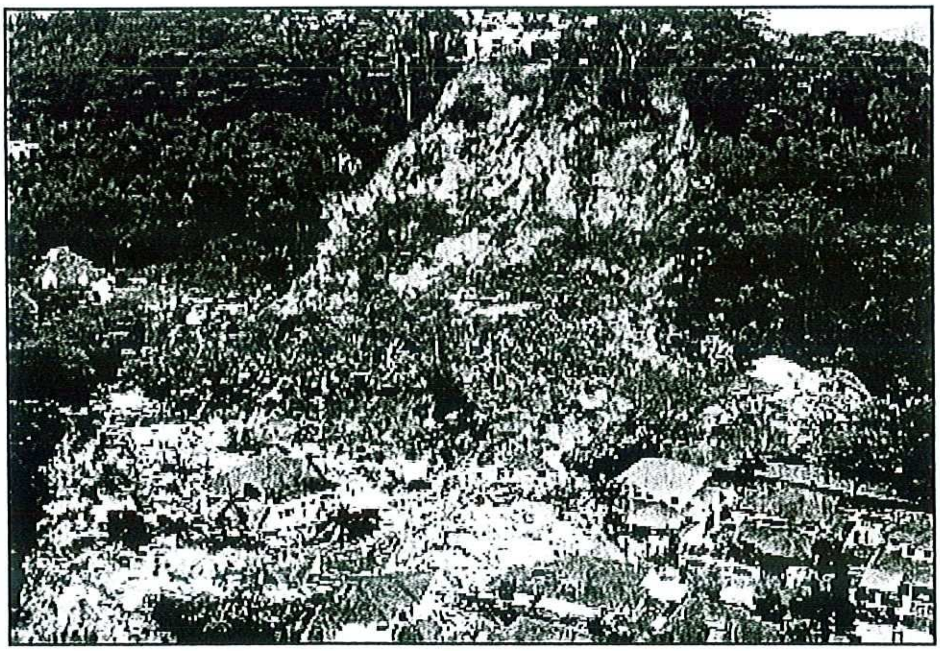

Figure 1: Overall view of the landslide location

An area of approximately four (4) hectares of land was affected. The affected areas were Taman Bukit Mewah, Jalan Bukit Antarabangsa, Jalan Wangsa 11 and Jalan Wangsa 9 of Taman Wangsa Ukay, Jalan Bukit Jaya 6A of Taman Bukit Jaya, Impian Selatan Condominium and Kyoto Garden Condominium.

This report shall be read in conjunction with the Final Landslide Investigation Report Volume II: Appendices.

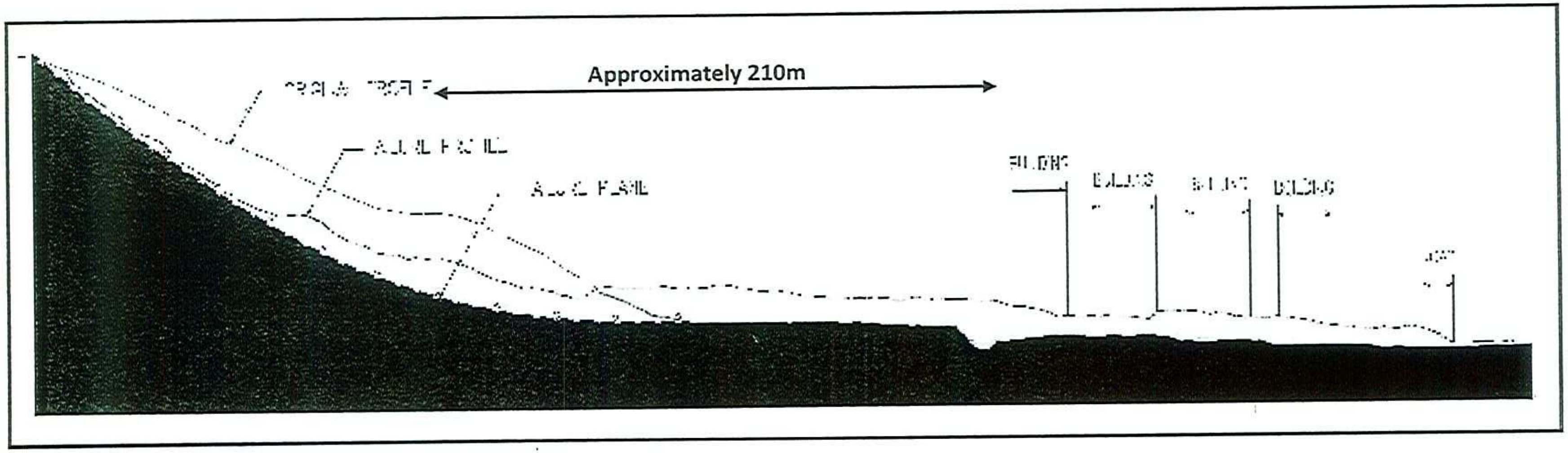

Figure 2: Cross-Section showing the estimated failure plane and failure run-out distance of 210m (as defined in the figure).

2.0 COMMITTEE MEMBERS

A special committee was formed to carry out the landslide investigation works. The committee consisted of various agencies and was led by Slope Engineering Branch of the Public Works Department (Cawangan Kejuruteraan Cerun JKR-CKC). The committee members involved were from various agencies as follows:-

a) Public Works Department (Jabatan Kerja Raya)

   i. Slope Engineering Branch (Cawangan Kejuruteraan Cerun-CKC) – Dato' Ir. Dr. Ashaari Bin Mohamad and Ahmad Shuhaimi Ibrahim

   ii. Road and Geotechnical Engineering Branch (Cawangan Kejuruteraan Jalan dan Geoteknik-CKJG) – Dr. H. M. Aziz Bin K. M. Hanifah and Ir. Mohamad Nor Bin Omar

   iii. Civil, Structure and Bridge Engineering Branch (Cawangan Kejuruteraan Awam, Struktur dan Jambatan–CKASJ) – Ir.Ihsan Bin Atan

b) Minerals and Geoscience Department Malaysia (Jabatan Mineral Dan Geosains Malaysia-JMG) – En. Zakaria Bin Mohamad and En. Syed Bin Omar

c) Department of Surveying and Mapping Malaysia (Jabatan Ukur Dan Pemetaan Malaysia-JUPEM) – En. Mohamad Sofian Bin Abu Talib

d) Department of Irrigation and Drainage (Jabatan Pengairan Dan Saliran-JPS) – En. Abu Hanafiah Bin Ramli

e) Department of Environment Malaysia (Jabatan Alam Sekitar-JAS) – Pn. Zuhainim Abdul Ghafar

f) Malaysian Meteorological Department (Jabatan Meteorologi Malaysia-JMM) – En. Tan Huri Vein

g) Malaysian Remote Sensing Agency (Agensi Remote Sensing Malaysia-ARS) – En. Shahrudin Bin Ahmad

h) Local Government Department (Jabatan Kerajaan Tempatan-JKT) - En. She Tian Hock

i) Ampang Jaya Municipal Council (Majlis Perbandaran Ampang Jaya-MPAJ) – En. Hasrolnizam Bin Saari

j) Kumpulan IKRAM Sdn Bhd – KISB – Prof Dr. Mahadzer Mahmud

Individuals known to be consultants in the field of slope engineering were also included in this special committee, they were:

a) Ir. Dr. Mohd Asbi Othman (Mohd Asbi & Associates-MAA)

b) Ir. Dr. Nik Ramlan (ENCEAL Consultants Sdn Bhd-ECSB)

3.0 OBJECTIVES OF FAILURE INVESTIGATION

The objectives of this Final Landslide Investigative Report are as follows:-

a) to identify the probable cause(s) of the landslide.

b) to identify probable factors contributing to the landslide.

c) to explain the mode and mechanism of the landslide.

d) to provide information that would assist in the short-term and long-term remedial measures.

e) to determine immediate recommendations for areas of high risk.

4.0 THE SITE

The landslide occurred at Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang in the state of Selangor, approximately 7.20km from the Kuala Lumpur City Centre (KLCC) (see **Figure 3** and **Figure 4**). This area has been under the jurisdiction of the Local Authority of Majlis Perbandaran Ampang Jaya (MPAJ) since its inception in 1992. It is located approximately 1.4km from the Highland Towers site which toppled in December 1993.

The landslide is located between three (3) residential developments, i.e., Taman Wangsa Ukay (at the crest), Taman Bukit Mewah (at the toe) and Taman Bukit Jaya (refer **Figure 4**).

Above the affected bungalows (Taman Bukit Mewah), several link houses by Messrs. Superview Sdn Bhd which have been abandoned since 1985 are located between Jalan Wangsa 9 at the crest of the landslide and Jalan Bukit Antarabangsa at the toe of the landslide (see **Figure 4**).

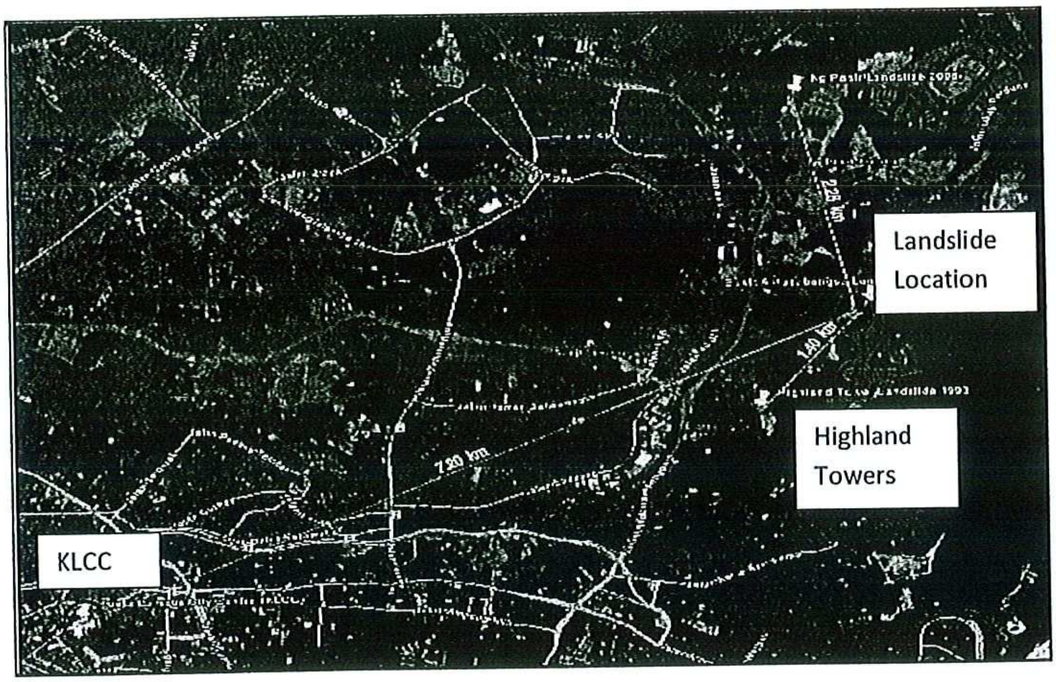

Figure 3: Site location

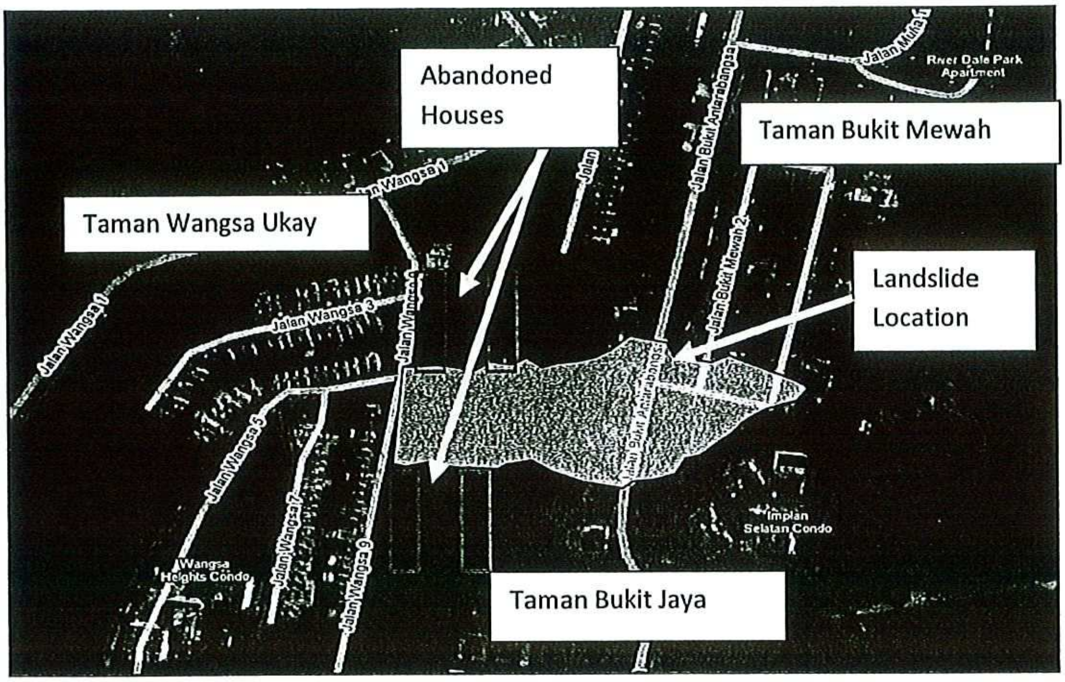

Figure 4: Location of the landslide at Bukit Antarabangsa

The development of the houses (marked in red above) by Messrs. Superview Sdn Bhd started in the 1980s. Slope failures were reported during the construction of these residential houses at which point the developer finally decided to abandon them. Chronological events relating to the site are as follows:-

Date	Event
14 Dec 1984	Slope failure at Block 13
22 Aug 1985	Slope failure at the end of Jalan Wangsa 9 at Block 12
14 Oct 1985	Signs of distress were detected along Jalan Wangsa 9, with visual cracks stretching approximately from Lots 6280 to 6287 of Block 13
8 Nov 1985	Blocks 13 and 16 collapsed
6 Dec 2008	Landslide took place at the same location of Blocks 13 and 16 which collapsed in 1985

Table 1: Chronology of failure events of the abandoned houses (see also Figure 5)

Note:

a) These chronological events were extracted from the "Geotechnical Design Report of the Proposed Development Between Jalan Wangsa 9 and Wangsa 11, Wangsa Ukay, Off Jalan Ulu Klang, Mukim Ulu Klang, Daerah Gombak, Selangor" for Messrs. Superview Development Sdn Bhd by Messrs. G&P Geotechnics Sdn Bhd.

b) The location of the housing/building blocks is as shown in the development plan in **Figure 5**.

Figure 5: Initial development plan by Messrs. Superview Development Sdn Bhd

5.0 INVESTIGATION PLAN

In order to achieve the objectives in **Section 3.0** above, the following investigation plan was outlined:

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

e) Identifying pore water pressure conditions at failure.

The mode & mechanism of failure (actual events) were supported by back analyses to ensure the causes and contributing factors of the landslide were effectively identified. The following works were undertaken to achieve this:

a) Desk study to review all relevant documents, the S.I reports, as-built drawings, aerial photographs, rainfall records, etc.

b) Surface investigation works, which included:
   I. geomorphological and geological mapping
   II. detailed Terrestrial LiDAR Survey (TLS) at failure area
   III. topographical survey of the affected and surrounding areas
   IV. post aerial photography
   V. a study on drainage network of the failure area and its vicinity

c) Subsurface investigation works, which included borehole investigation, continuous Mazier samplings, resistivity and seismic surveys, permeability tests and laboratory tests.

d) Instrumentation works which included inclinometers, movement markers and piezometers.

The detailed investigation plan for this study is summarized in the flowchart shown in **Figure 6**.

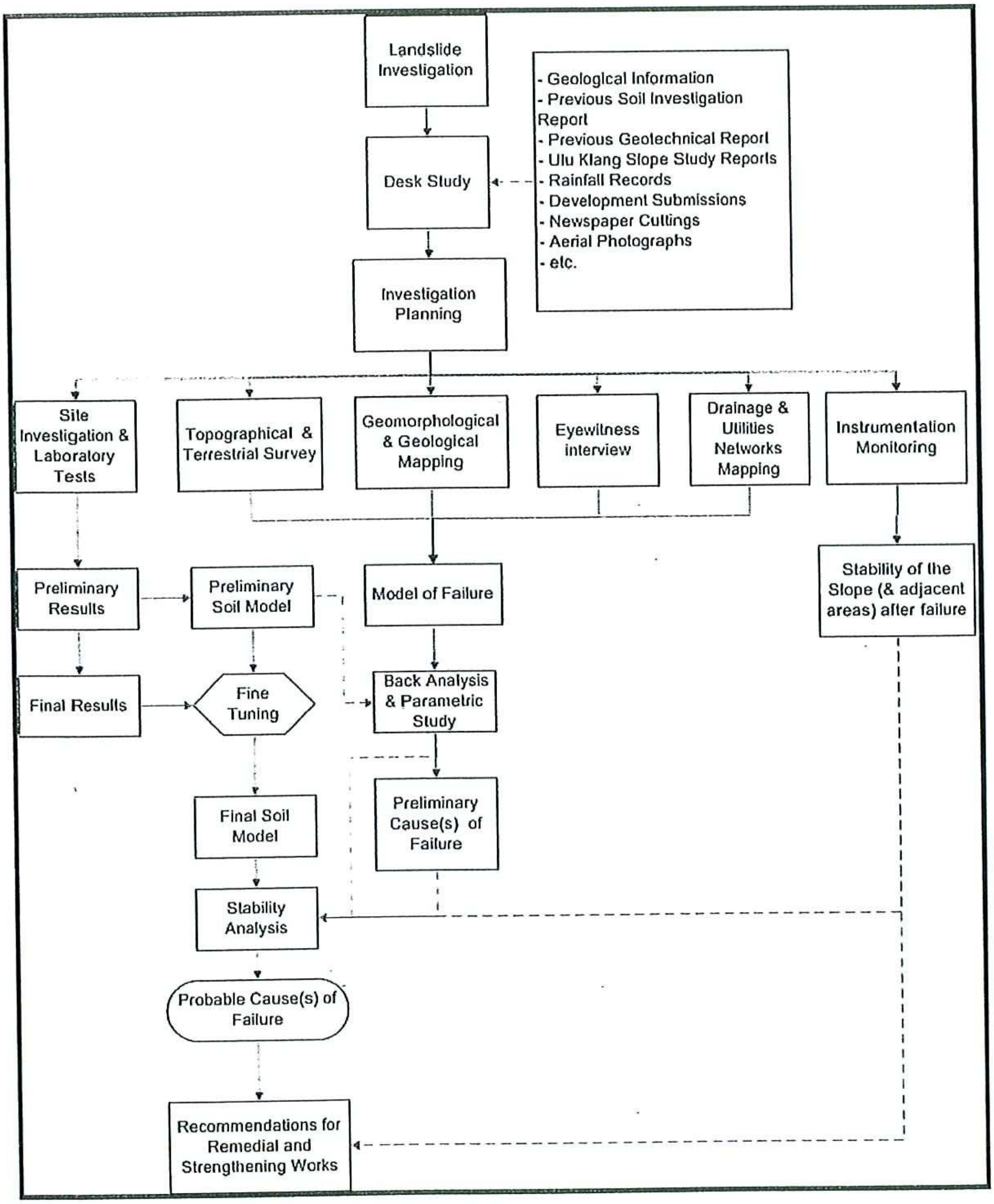

Figure 6: Flowchart of the investigation plan

6.0 AVAILABLE INFORMATION/ DATA TO DATE

The following information and data were made available during the preparation of this Final Landslide Investigation Report:-

6.1 <u>Information/ Data before Landslide (Pre-Landslide Data)</u>

a) Aerial Photographs dated 1966, 1968, 1974, 1975, 1981, 1985,1989, 1992, 1997, 1999, 2002, 2003 obtained from JUPEM.

b) Ortho-rectified Aerial Photograph dated 2007 obtained from Ulu Klang Ampang Hazard Assessment Study conducted in September 2007 by CKC-JKR.

c) Geomorphological Map and Data of the Area Before Failure (data obtained from Ulu Klang Ampang Hazard Assessment Study dated 2008 prepared by CKC-JKR).

d) Rainfall Records from Ampang Ulu Langat station, Klang Gate Station, Subang Station and Petaling Station from 1st November to 7th December 2008 obtained from JMM.

e) Subsurface Investigation Report by Messrs. Majumec Bina Sdn Bhd dated October 2003 for "The Proposed Development of Linkhouses Between Jalan Wangsa 9 and Wangsa 11, Wangsa Ukay, Off Jalan Uluk Klang, Mukim Ulu Klang, Daerah Gombak, Selangor for Messrs Superview Development Sdn Bhd".

f) Geotechnical Design Report by Messrs. G&P Geotechnics Sdn Bhd dated 2006 for "The Proposed Development of Linkhouses Between Jalan Wangsa 9 and Wangsa 11, Wangsa Ukay, Off Jalan Uluk Klang, Mukim Ulu Klang, Daerah Gombak, Selangor for Messrs Superview Development Sdn Bhd".

g) Water Reticulation Plan of Bukit Antarabangsa dated December 2008 from SYABAS.

h) Bukit Antarabangsa Sewer Layout Plan by MPAJ (no date specified).

i) Field Findings Report:- Ulu Klang Ampang Slope Hazard Assessment Study dated January 2009 by CKC-JKR.

6.2 Information/ Data after Landslide (Post-Landslide Data)

a) Aerial photograph dated 16th December 2008 taken by JUPEM after the landslide.

b) Site Investigation Report Volumes I, II and III (Reference No: IRDC/08/B25/106) dated February 2009 prepared by Kumpulan IKRAM Sdn Bhd.

c) Preliminary Geology Report of Bukit Antarabangsa Landslide dated January 2009 (Ref No: JMG.SWP>GS(KJ)1/2009) prepared by Minerals and Geoscience Department Malaysia.

d) "Eyewitness Account Interviews: Transcription, Bukit Mewah, Bukit Antarabangsa Landslide" dated March 2009 prepared by Cawangan Kejuruteraan Cerun (CKC-JKR).

e) "Laporan Awal Kejadian Tanah Runtuh di Taman Bukit Mewah, Bukit Antarabangsa, Selangor" dated 9th December 2008 (Ref No: JKR 21501-B003-08) by CKC-JKR.

f) "Dokumen-dokumen Yang Berkaitan Bagi Pembangunan Taman Wangsa Ukay Volume 1, Volume 1 Jilid 2 and Jilid 3" ranging between the years 1983 to 2007 from Ampang Jaya Municipal Council-MPAJ.

g) "Dokumen-dokumen Yang Berkaitan Bagi Pembangunan Taman Bukit Mewah Volume 2, Volume 2 Jilid 2 and Volume 2 Jilid 3" ranging between the years 1989 to 1993 from Ampang Jaya Municipal Council-MPAJ.

h) "Dokumen-dokumen Yang Berkaitan Bagi Pembangunan Taman Bukit Jaya Volume 3" for the year 1989 from Ampang Jaya Municipal Council-MPAJ.

i) "Laporan Pemantauan Kawasan Sekitar Bukit Antarabangsa, Ampang, Selangor Darul Ehsan (Taman Puncak Utama)" dated 16th December 2008 (Reference No: IRDC/08/B21/101C) prepared by Kumpulan IKRAM Sdn Bhd.

j) "Laporan Pemantauan Kawasan Sekitar Bukit Antarabangsa, Ampang, Selangor Darul Ehsan (Jalan B.U 1/1, Taman Bukit Utama)" dated 16th December 2008 (Reference No: IRDC/08/B21/101B) prepared by Kumpulan IKRAM Sdn Bhd.

k) "Laporan Pemantauan Kawasan Sekitar Bukit Antarabangsa, Ampang, Selangor Darul Ehsan (Laman Oakleaf)" dated 19th December 2008 (Reference No: IRDC/08/B21/101F) prepared by Kumpulan IKRAM Sdn Bhd.

l) "Laporan Pemantauan Kawasan Sekitar Bukit Antarabangsa, Ampang, Selangor Darul Ehsan (Siarah Oakleaf, Jalan Wangsa 5)" dated 16th December 2008 (Reference No: IRDC/08/B21/101D) prepared by Kumpulan IKRAM Sdn Bhd.

m) "Laporan Pemantauan Kawasan Sekitar Bukit Antarabangsa, Ampang, Selangor Darul Ehsan (Jalan Wangsa 3)" dated 16th December 2008 (Reference No: IRDC/08/B21/101A) prepared by Kumpulan IKRAM Sdn Bhd.

n) "Technical Report on Landslide Incident at Bukit Antarabangsa on 6th December 2008" dated December 2008 prepared by DID Investigation Technical Committee for Bukit Antarabangsa Landslide Incident, Department of Irrigation and Drainage Malaysia.

o) "Laporan Awalan Kejadian Tanah Runtuh Di Taman Bukit Mewah, Bukit Antarabangsa, Mukim Ulu Kelang, Daerah Gombak, Selangor (Status Keselamatan Tapak: Interim 1-Revision 1)" dated 16th December 2008 (Ref No: (909)IRDC/08/B25/106) prepared by Kumpulan IKRAM Sdn Bhd.

p) "Laporan Pemantauan Instrumentasi Bagi Kajian Tanah Runtuh Di Taman Bukit Mewah, Bukit Antarabangsa, Mukim Ulu Kelang, Daerah Gombak, Selangor (Interim Pemantauan 1)" dated 24th December 2008 (Ref No: (905)IRDC/08/B25/106) prepared by Kumpulan IKRAM Sdn Bhd.

q) "Laporan Pemantauan Instrumentasi Bagi Kajian Tanah Runtuh Di Taman Bukit Mewah, Bukit Antarabangsa, Mukim Ulu Kelang, Daerah Gombak, Selangor (Status Keselamatan Tapak: Interim Pemantauan 2)" dated 14th January 2009 (Ref No: (053)IRDC/08/B25/106) prepared by Kumpulan IKRAM Sdn Bhd.

r) "Laporan Penilaian Tahap Kebolehruntuhan Tanah dan Kebolehakisan Hujan Tragedi Tanah Runtuh Di Taman Bukit Mewah, Bukit Antarabangsa, Hulu Kelang, Selangor" dated 7th January 2009 prepared by International Research Centre on Disaster Prevention, UiTM International Centre.

s) "Geology Report of Bukit Antarabangsa Landslide, Hulu Kelang, Selangor Darul Ehsan" dated February 2009 (Ref No: JMG.SWP.GS(KJ)2/2009) prepared by Minerals and Geoscience Department Malaysia.

7.0 DESK STUDY

During the desk study, all relevant documents as mentioned in **Section 6.0** were reviewed.

7.1 Aerial Photographs by Department of Surveying and Mapping Malaysia (JUPEM)

A series of aerial photographs from years 1966 to 2003 were provided by JUPEM. Additional aerial photographs dated 2007 were obtained from Ulu Klang Slope Assessment Study conducted by CKC-JKR. The following write-up shows a series of aerial photographs describing the progressive development that had taken place over the years (between 1968 to 2008) at the failure area.

7.1.1 Aerial Photograph 1968

The aerial photograph (1968) shows some clearing works that had been taking place at the area surrounding the failure site (see **Figure 7a**).

7.1.2 Aerial Photographs 1974 and 1975

Based on the aerial photographs (1974 and 1975), it is quite clear that there had been massive earthworks' activity at the crest of the failed slope. The aerial photograph taken in 1975 also shows signs of earth dumping around the perimeter of the landslide (see **Figure 7b** and **7c**). In general, the earth dumping was not compacted and loose in nature.

7.1.3 Aerial Photograph 1985

Aerial photograph of 1985 shows the progress of Wangsa Ukay development by the developer, Superview. It can be seen here that the platforms for the link house units were being prepared (see **Figure 7d**).

7.1.4 Aerial Photograph 1992

In 1992, the aerial photograph shows that three (3) rows of link houses were completed (although by then they were abandoned) while the other three (3) rows were not visible. Out of those three (3) invisible rows of link houses, two (2) rows had fell within the current area of the landslide (see **Figure 7e**).

7.1.5 Aerial Photographs 1999, 2003, 2007 and 2008

Aerial photographs of 1999, 2003 and 2007 show that thick vegetation had completely covered the areas around the abandoned houses. One (1) row of the abandoned houses can no longer be seen in the aerial photographs as it is probably hidden in the dense vegetation (see **Figures 7f, 7g** and **7h**). Aerial photograph of 2008 shows the landslide scar (see **Figure 7i**).

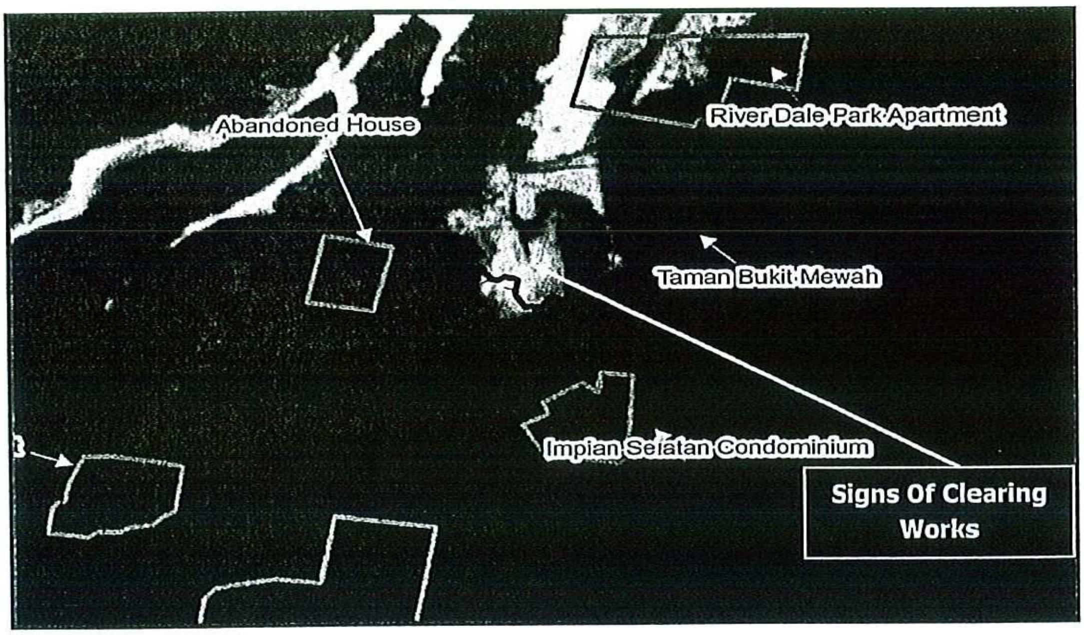

Figure 7a: Aerial photograph taken in 1968

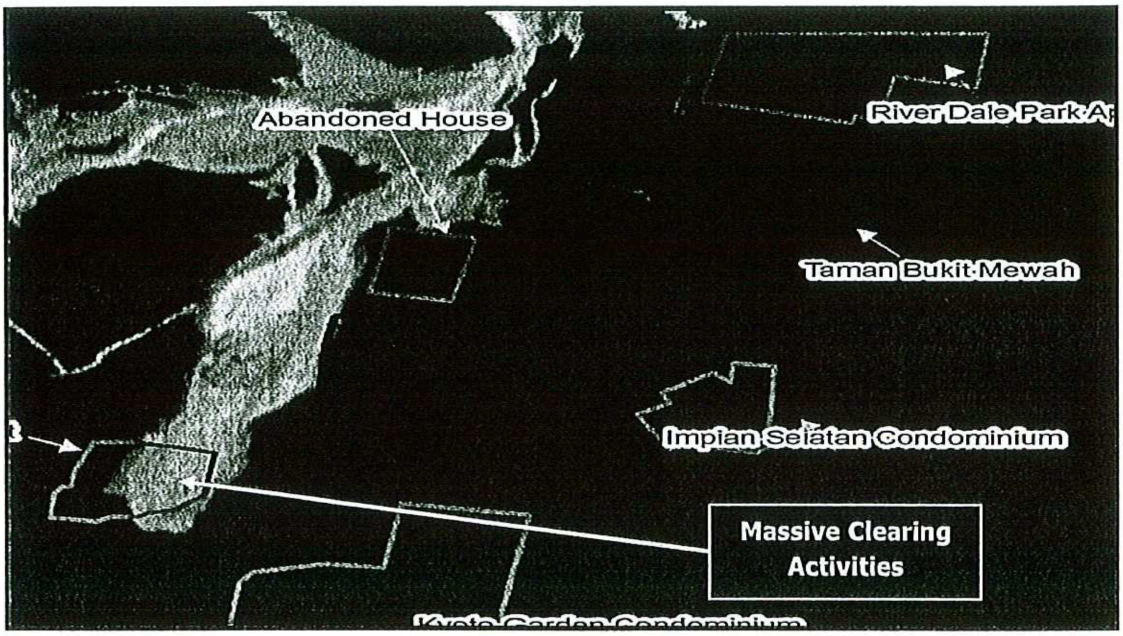

Figure 7b: Aerial photograph taken in 1974

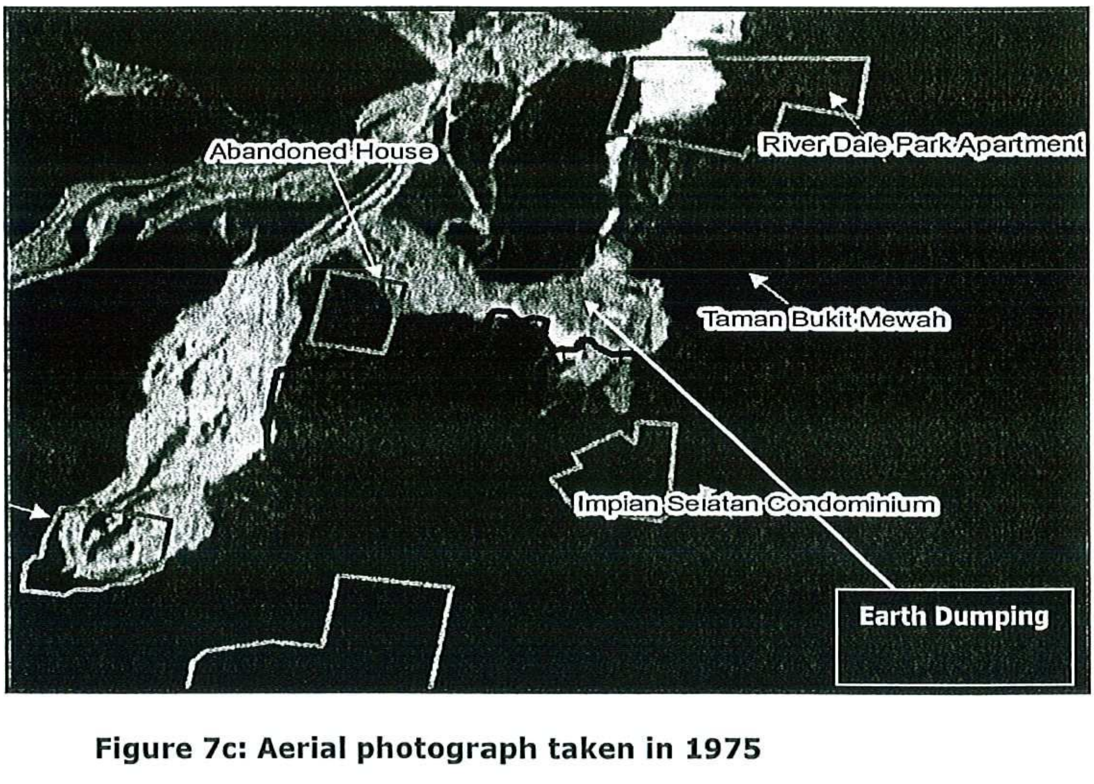

Figure 7c: Aerial photograph taken in 1975

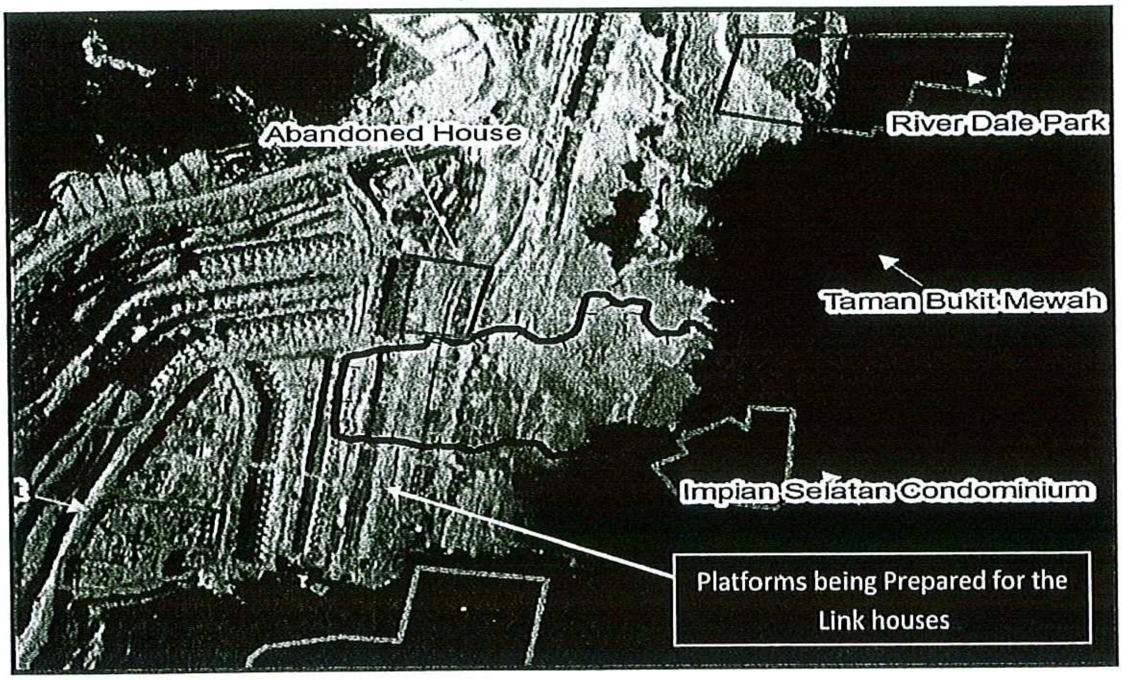

Figure 7d: Aerial photograph taken in 1985

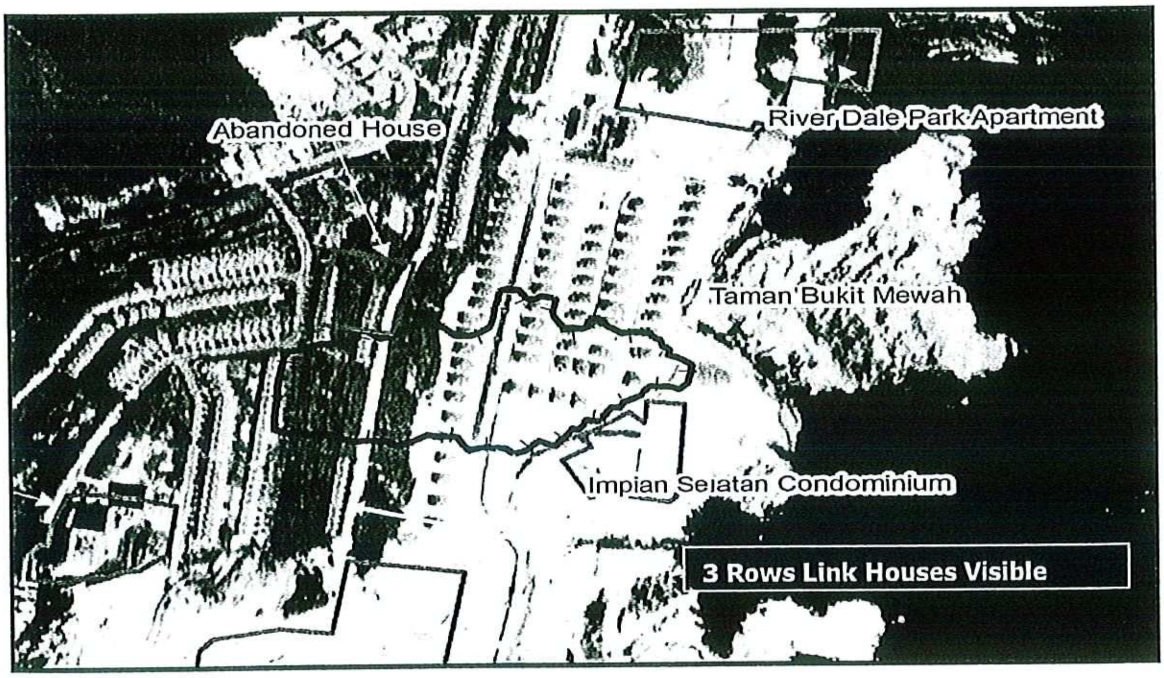

Figure 7e: Aerial photograph taken in 1992

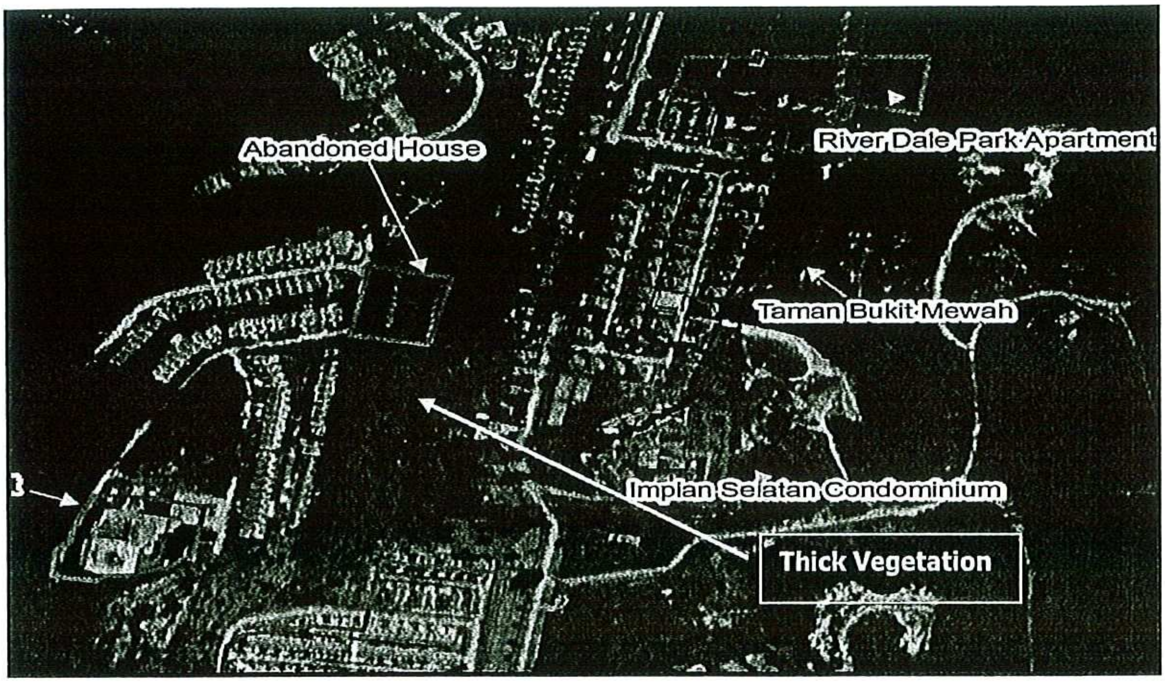

Figure 7f: Aerial photograph taken in 1999

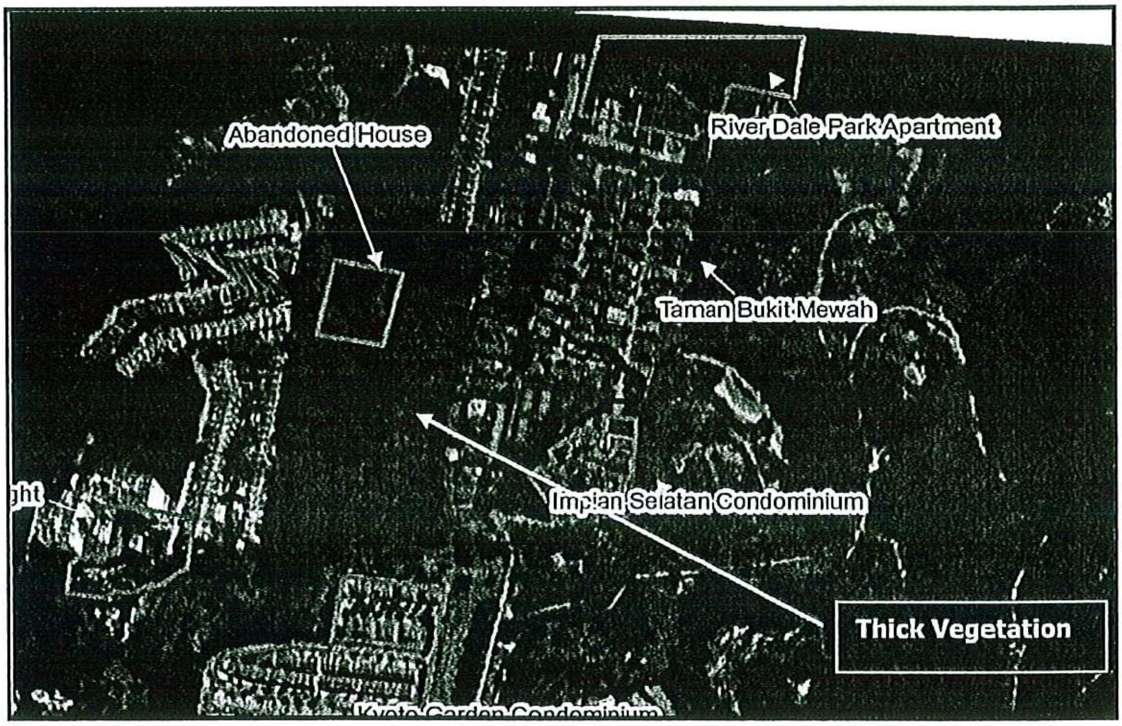

Figure 7g: Aerial photograph taken in 2003

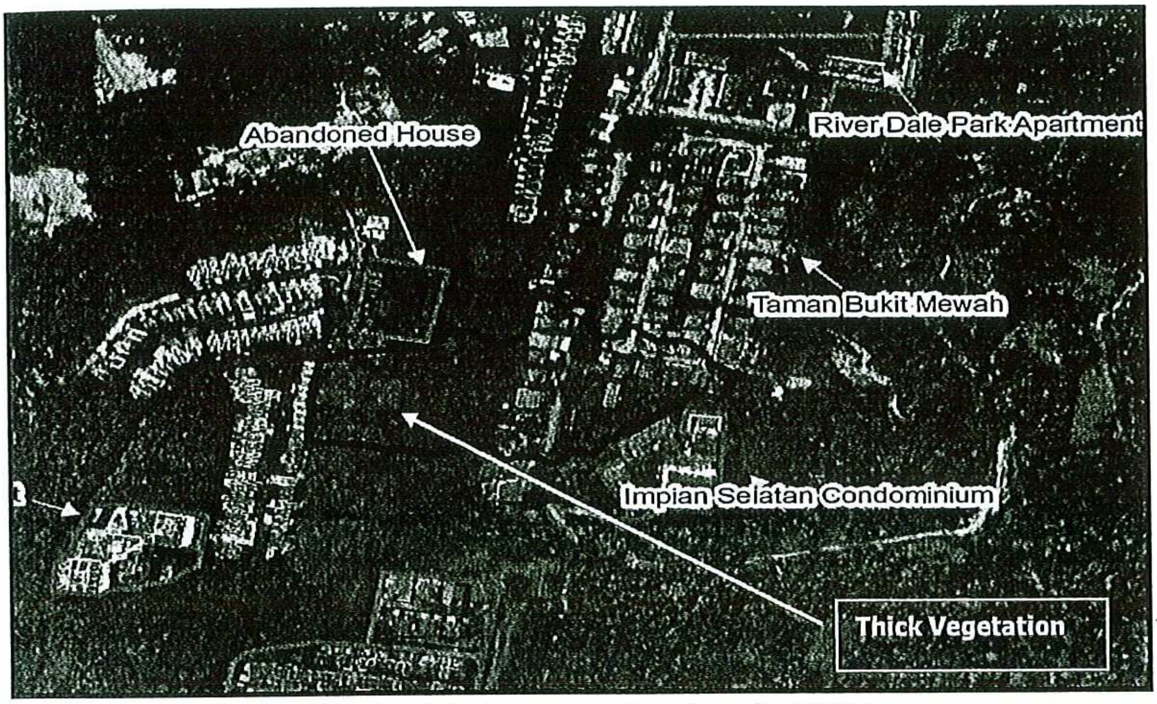

Figure 7h: Aerial photograph taken in 2007

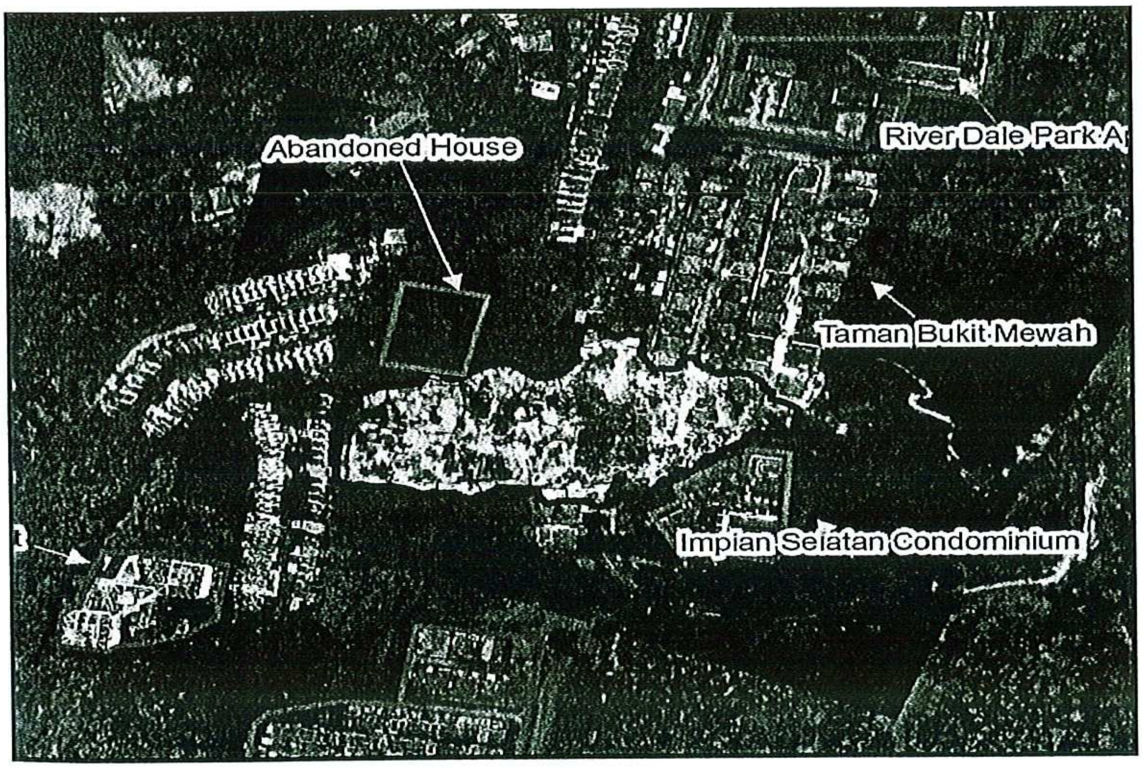

Figure 7i: Aerial photograph taken in 2008

7.2 Aerial Photographs Interpreted by Minerals and Geoscience Department Malaysia (JMG)

A series of aerial photographs from years 1966 to 2008 were interpreted by JMG. The detailed report is listed in **Section 6.2(s)** and referred to in the following write-up.

7.2.1 Aerial Photograph 1966

Development in the Bukit Antarabangsa area commenced long before 1966. Aerial photographs from 1966 show some land clearing activities and earthworks that had taken place (see **Figure 7j**); this is indicated by the spotted white area along part of Sungai Seriang.

The hill ridges, Sungai Seriang and its tributaries can be identified at their original location through aerial photography. Sungai Seriang originally flowed through from south to north of the area. There were also streams flowing over the slopes and the landslide area.

7.2.2 Aerial Photograph 1981

In 1981, there was an increase in the clearing works at the landslide area (see **Figure 7k**). There were more cuttings carried out. The clearing of the ridge areas had also increased as well as the size of the filled area.

A landslide had taken place during this time near the northwestern hillside adjacent to the recent Bukit Antarabangsa landslide. Erosion and debris can be seen at many locations along the new access road, which was being built on the western valley slope area.

7.2.3 Aerial Photograph 1989

From the 1989 aerial photograph, it can be seen that the western hillside and the ridge areas had undergone extensive development (see **Figure 7l**). Meanwhile, the eastern side of the hillslopes (towards north of Sungai Seriang) was undergoing more cutting and filling. The size of the filled area in the Sungai Seriang valley had increased.

Erosional features (debris) can be observed along the valley and the excavated eastern hillside. The erosion areas in 1989 appeared adjacent to where the recent landslide took place. Streams can only be observed at the eastern hillside of the area.

7.2.4 Aerial Photograph 1997

From the 1997 aerial photographs (see **Figure 7m**), it can be seen that the entire housing development by various developers in the Bukit Antarabangsa area had been completed. However, previous ridges and its surrounding areas were covered with thick vegetation. Rocky outcrops can be observed at the eastern portion of this area. 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.

7.2.5 Aerial Photographs 2002 and 2003

Aerial photograph of 2002 (see **Figure 7n**) shows that the crest of the recent failure was covered by dense vegetation. The rock outcrop on the eastern area was also similarly covered. Some stream lines can be seen forming at the western side of the area, especially at the crest of the recent failure.

Aerial photograph of 2003 (see **Figure 7p**) shows about the same vegetation formation as the year before. The stream lines that were once visible in 2002 now had formed gully erosions. The only visible stream line is located at northwestern side of the landslide area.

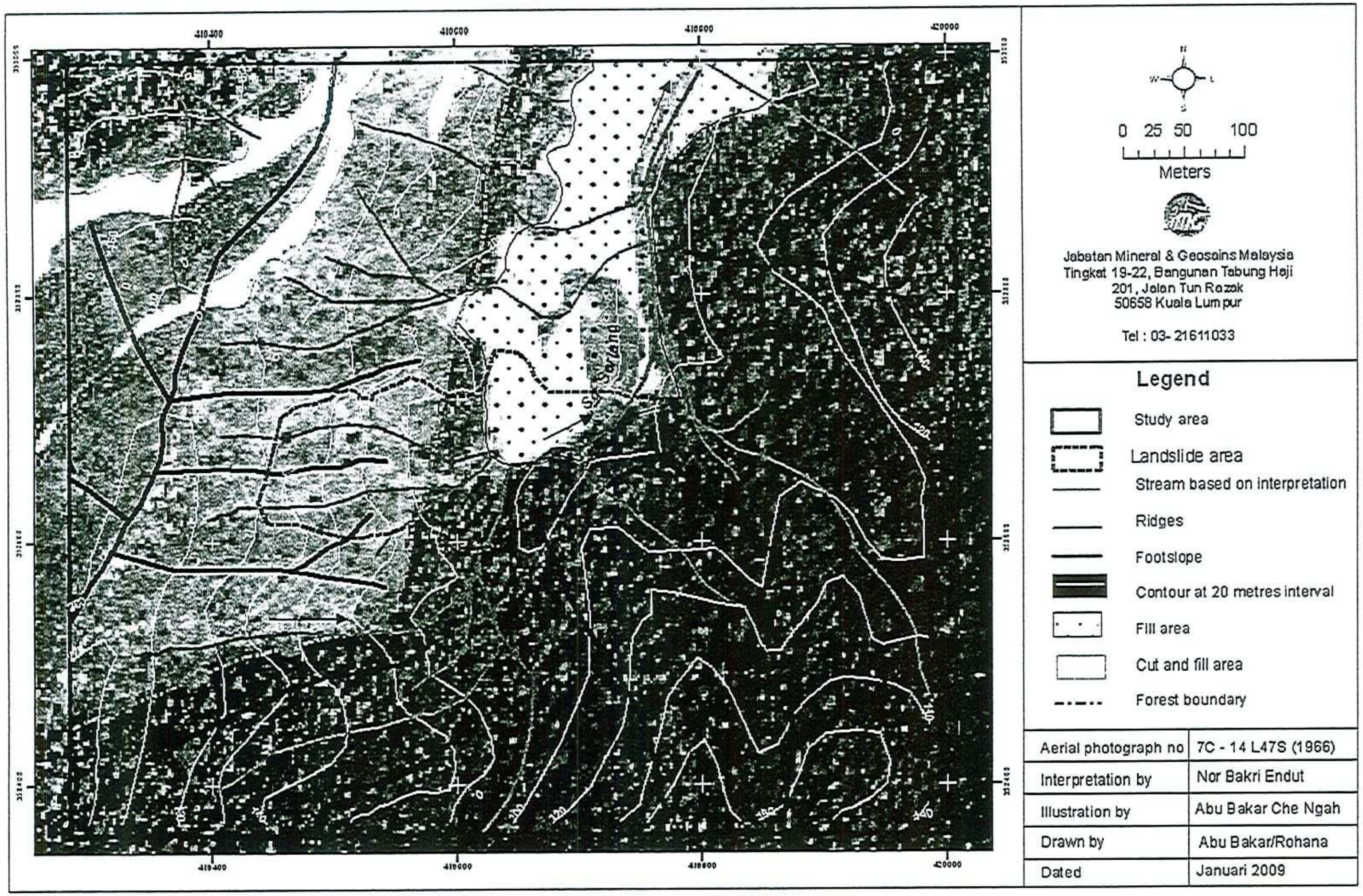

Figure 7j: Aerial photograph taken in 1966

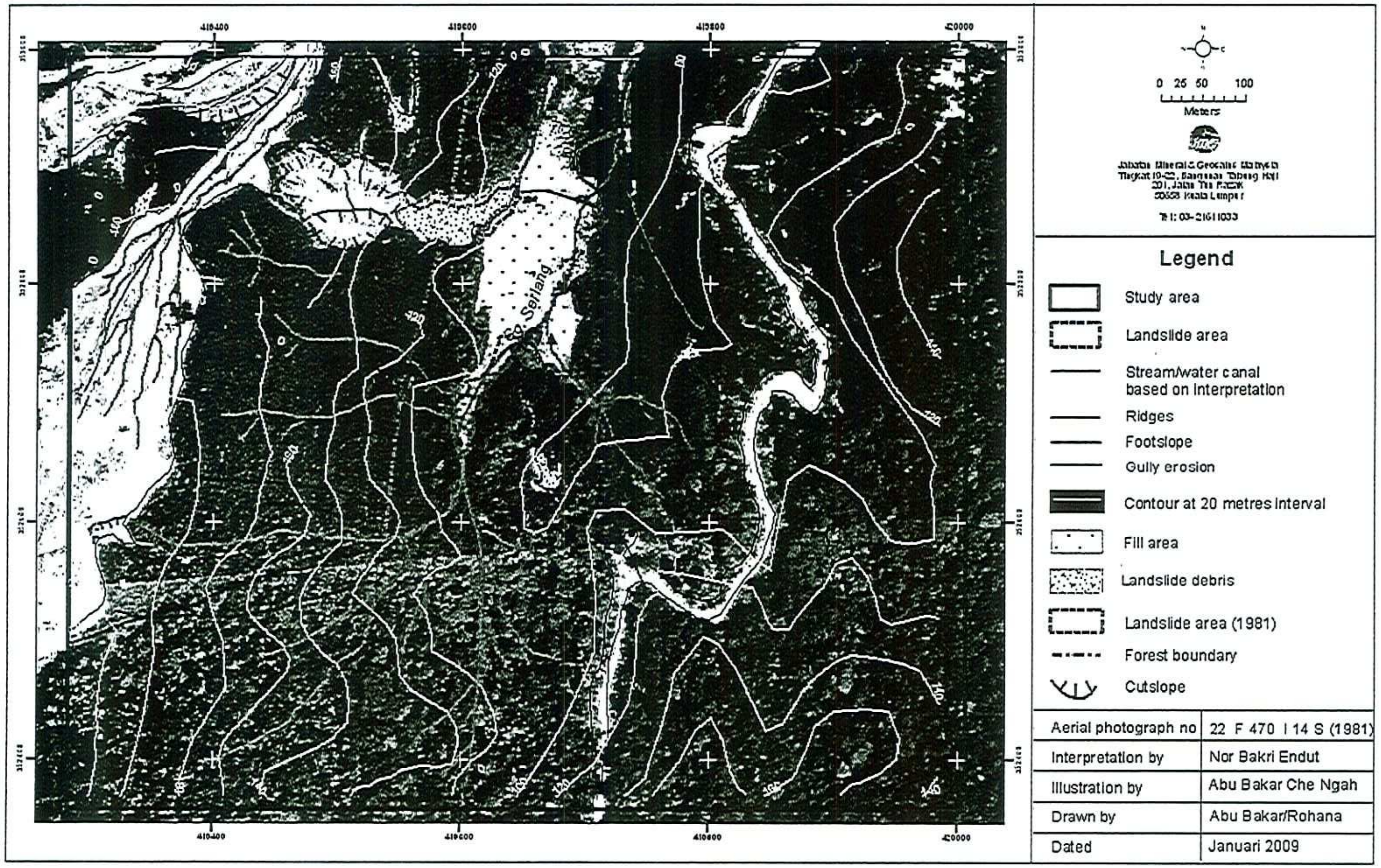

Figure 7k: Aerial photograph taken in 1981

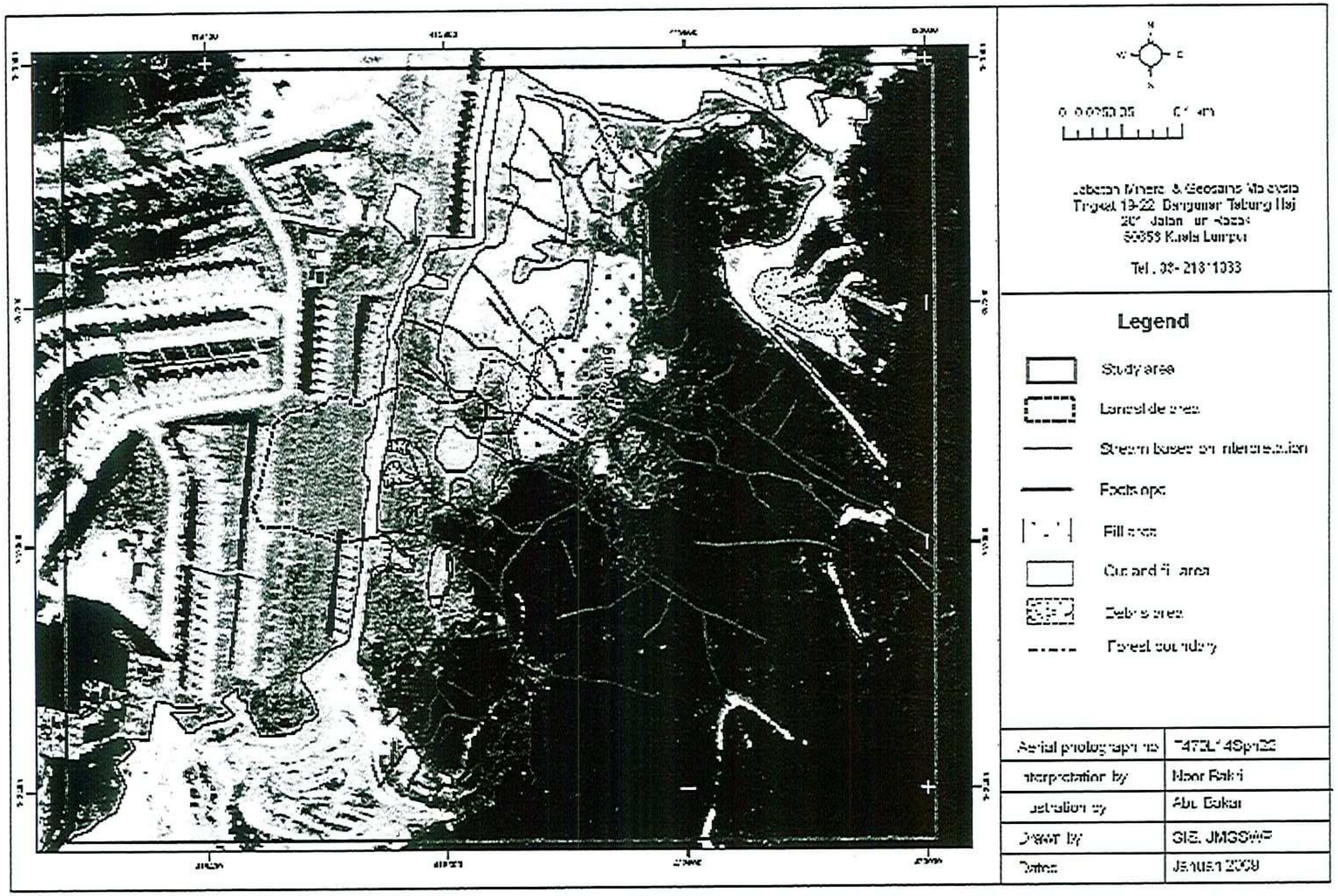

Figure 7l: Aerial photograph taken in 1989

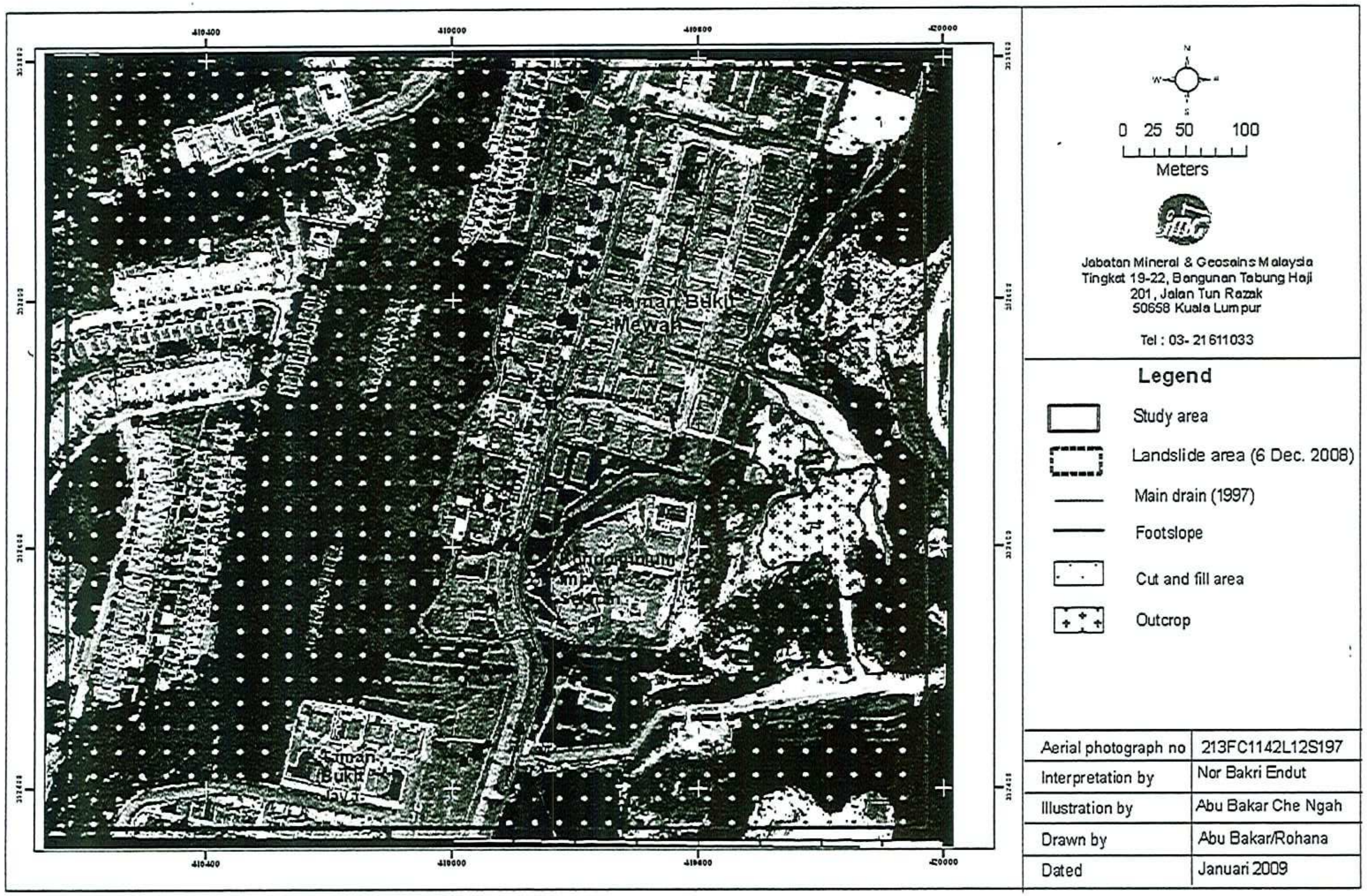

Figure 7m: Aerial photograph taken in 1997

Figure 7n: Aerial photograph taken in 2002

Figure 7p: Aerial photograph taken in 2003

7.3 Geology

The Geological Map of Selangor (Sheet 94) Kuala Lumpur 1:63,360 (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. The granite texture generally varies from coarse to medium grained, porphyritic to slightly porphyritic with color ranging from white to grey.

In general, the residual soils in this area are made up of residual granite at various stages of decomposition overlying the parent rock mass. The thickness of this weathered mass above the parent rock mass can be very thick; variable and usually interspersed with numerous granite boulders of various sizes. The simplified geological map of the site is shown in **Figure 8**.

Based on the Geology Report prepared by JMG, highly weathered and jointed granitic bedrock underlies the subsoil profile of the area. This is based on the nearest exposed outcrops found along Jalan Wangsa 1 and Jalan Wangsa 7 that were lightly jointed, with some loose blocks. The weathering grading indicates this granite as slightly weathered to residual soil (weathering grade of II–VI).

7.4 Hydrogeology

The water probe tests conducted by JMG are used to analyze the saturation of the ground at the failure area. Based on **Figure 9**, the highest water level depth (0m to 5m below ground level) is found at the mid level and the toe of the landslide area. The depth of the water level at the crest of the landslide area was between 5m to 15m below ground level.

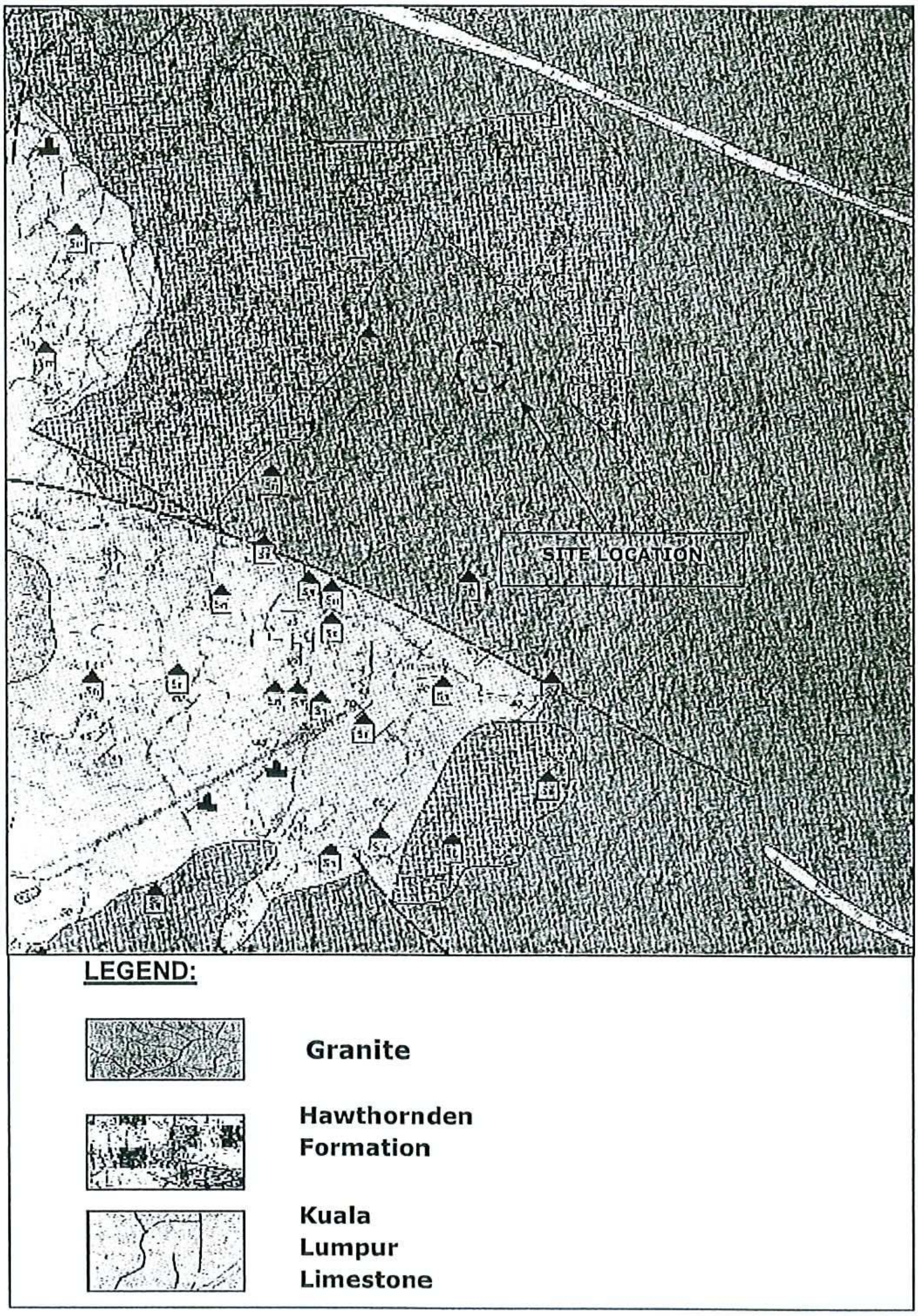

Figure 8: Geological map of the landslide area

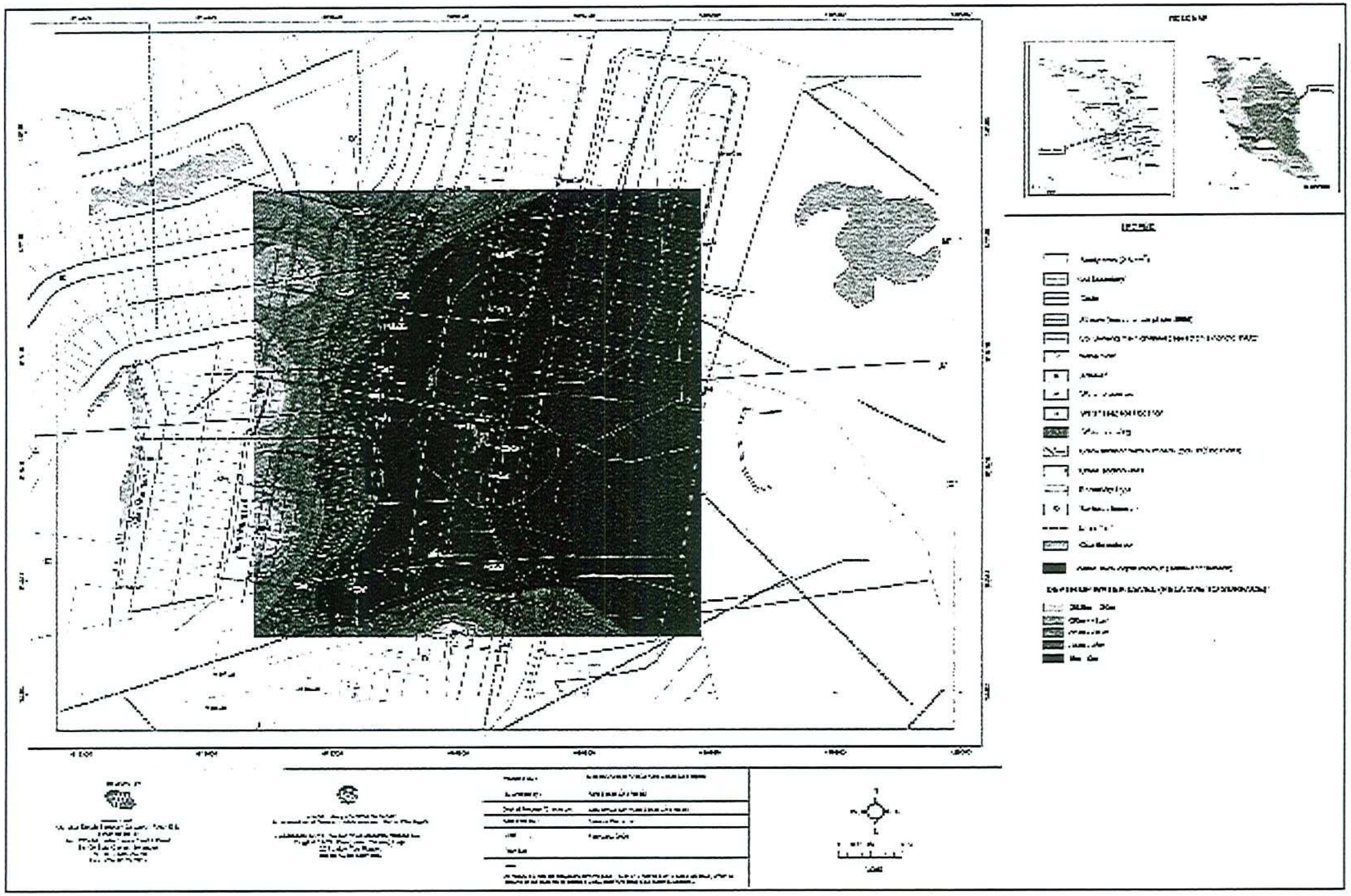

Figure 9: Hydrogeology map of the landslide area

7.5 Rainfall Records

Two (2) sets of rainfall data were made available during the investigation works. The rainfall data were obtained from:

a) Malaysian Meteorological Department (Jabatan Meteorologi Malaysia-JMM)

b) Department of Irrigation and Drainage (Jabatan Pengairan dan Saliran-JPS)

7.5.1 Analysis of Rainfall Data from the Department of Meteorology Malaysia (JMM)

Rainfall records from 1st November 2008 to 7th December 2008 were collected from four (4) nearest meteorological stations to the landslide site. They were:

a) Ampangan Ulu Langat Rainfall Station (03°13'N 101°52'E) which is approximately 12km away from the site.

b) Klang Gate Rainfall Station (03°14'N 101°45'E) which is approximately 6km away from the site.

c) Subang Rainfall Station (03°7' N 101°33'E) which is approximately 25km away from the site.

d) Petaling Jaya Rainfall Station (03°6'N 101°39'E) which is approximately 16km away from the site.

Klang Gate Station is found to be the nearest rainfall station to the failure site. The rainfall data here shows that in the first three weeks of November 2008, there was at least one day in each week where the rainfall was between 60mm to 70mm. However, just prior to the landslide, the rainfall records do not show high volume of rainfall, except for the rainfall station in Petaling Jaya (see **Figure 10**).

From the cumulative rainfall graph in **Figure 11**, the cumulative rainfall in Ulu Langat, Klang Gate and Petaling Jaya stations for the duration of 1st November 2008 to 7th December 2008 exceeds 500mm, except Ampangan Ulu Langat station which recorded only 350mm.

From the report entitled in **Section 6.1(d)** submitted by JMM, the monthly rainfall in the month of October 2008 and November 2008 is above the usual average which is close to the highest monthly rainfall ever recorded from 1980 to 2007. The 2-month (October – November) and 3-month (September – November) cumulative rainfalls were also found close to the highest cumulative amount recorded from year 1980 to 2007.

For detailed rainfall analysis, refer to the report entitled "**Laporan Meteorologi, Tanah Runtuh Di Bukit Antarabangsa Berlaku Pada 6 Disember 2008**" by JMM.

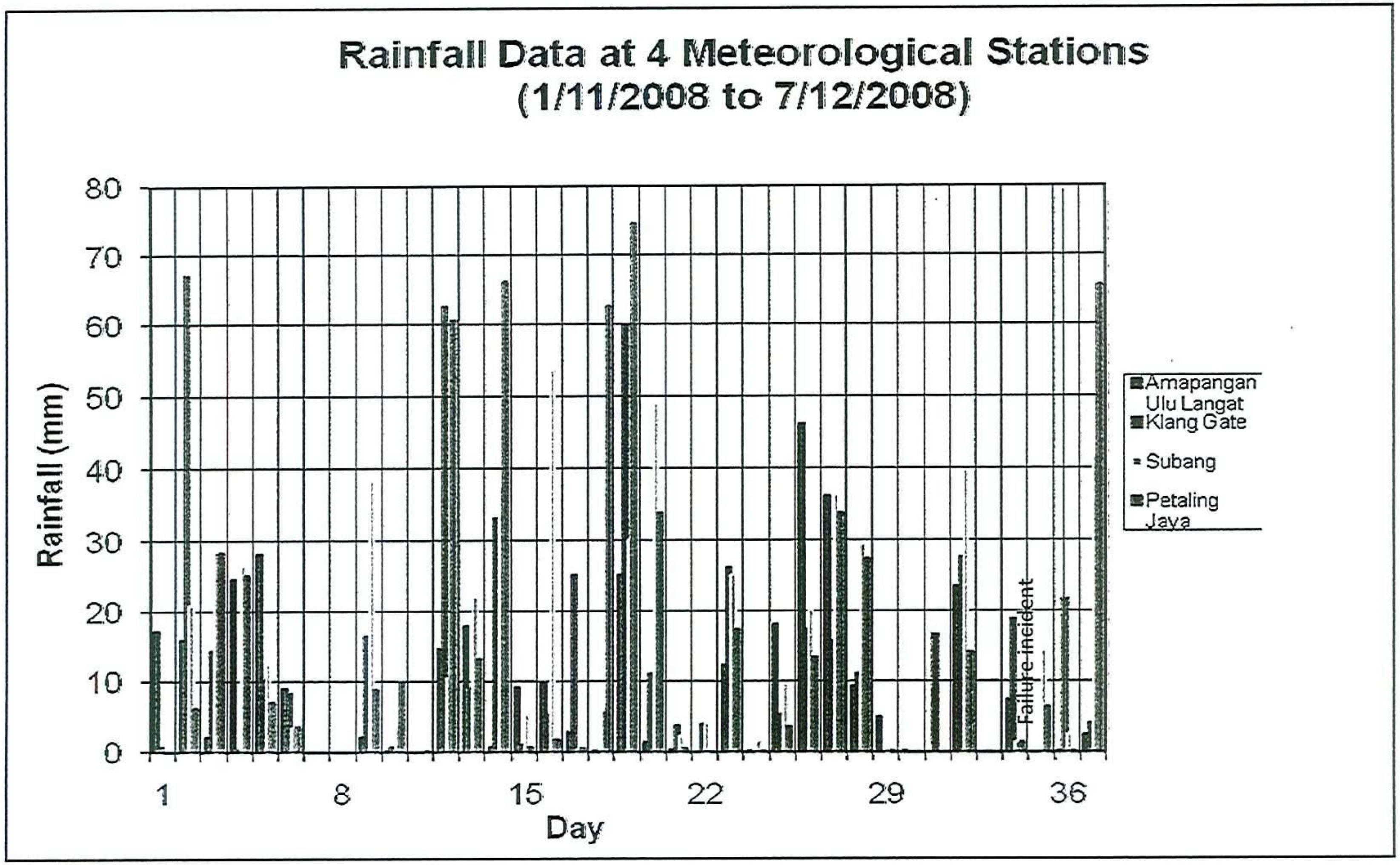

Figure 10: Rainfall pattern from 1/11/08 to 7/12/08 of the 4 (four) nearest stations to the landslide

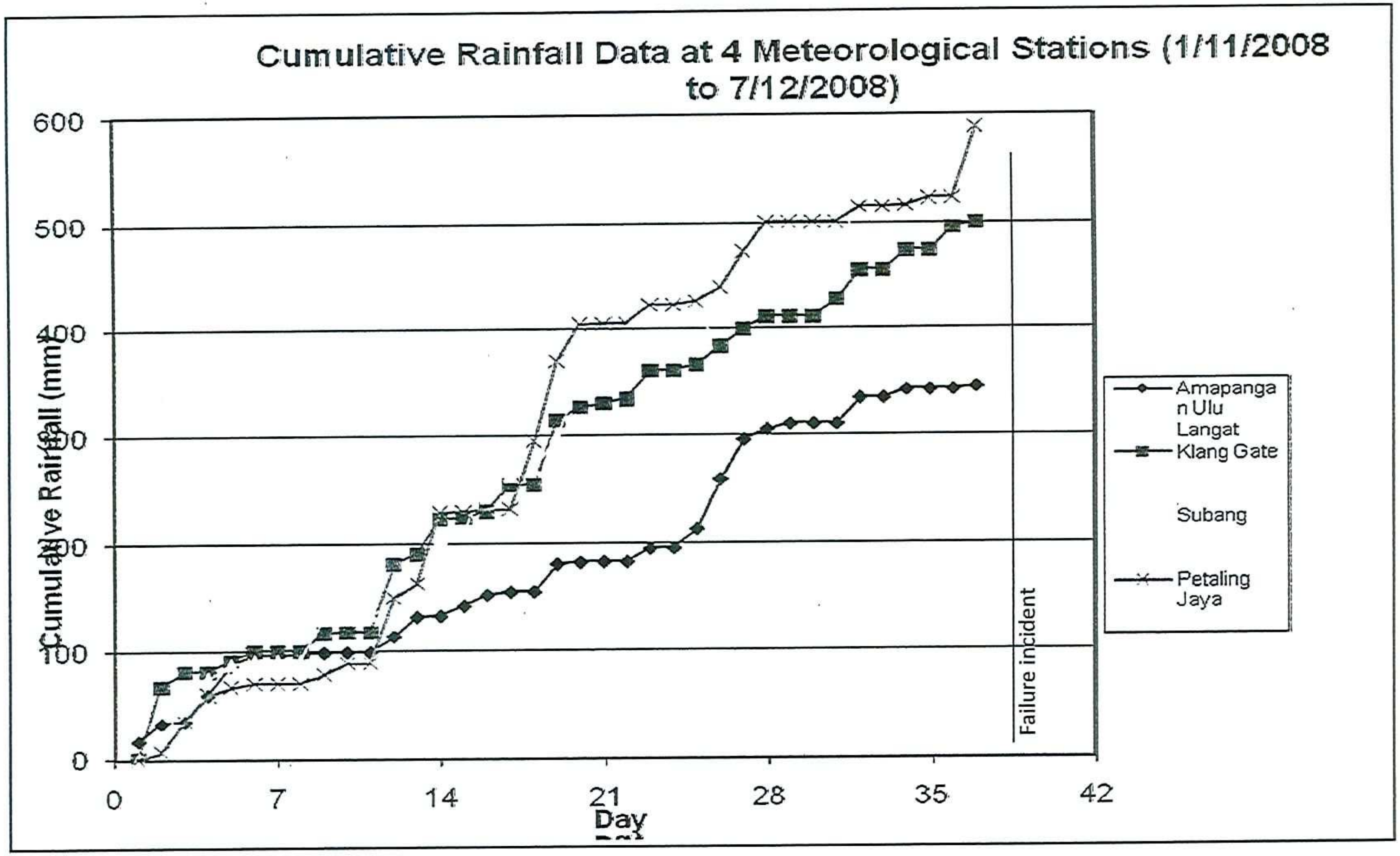

Figure 11: Cumulative rainfall from 1/11/08 to 7/12/08 of the 4 (four) nearest stations to the landslide

7.5.2 Analysis of Rainfall Data from the Department of Irrigation and Drainage Malaysia (JPS)

Two (2) nearest rainfall stations were used by JPS to carry out the rainfall analysis. The stations are:

a) Ampang Rainfall Station (03°9′ 20″N 101°45′ 00″E) which is approximately 3km from the site.

b) Bukit Antarabangsa Station (03°11′ 01″N 101°46′ 22″E) which is approximately 0.45km from the site.

The Bukit Antarabangsa Station was established in 2003 and has only a handful of data (cumulated up to less than five (5) years).

Figure 12 shows the monthly rainfall records obtained from Bukit Antarabangsa Station for years 2003 to 2008. 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 rainfall 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.

In the frequency analysis, the annual maximum rainfall for 1 day, 3 days, 4 days, 5 days, 6 days, 7 days, 14 days and 30 days were extracted from the JPS Ampang rainfall station. The results of the frequency analysis based on Gumbel Type 1 distribution are shown in **Table 2.**

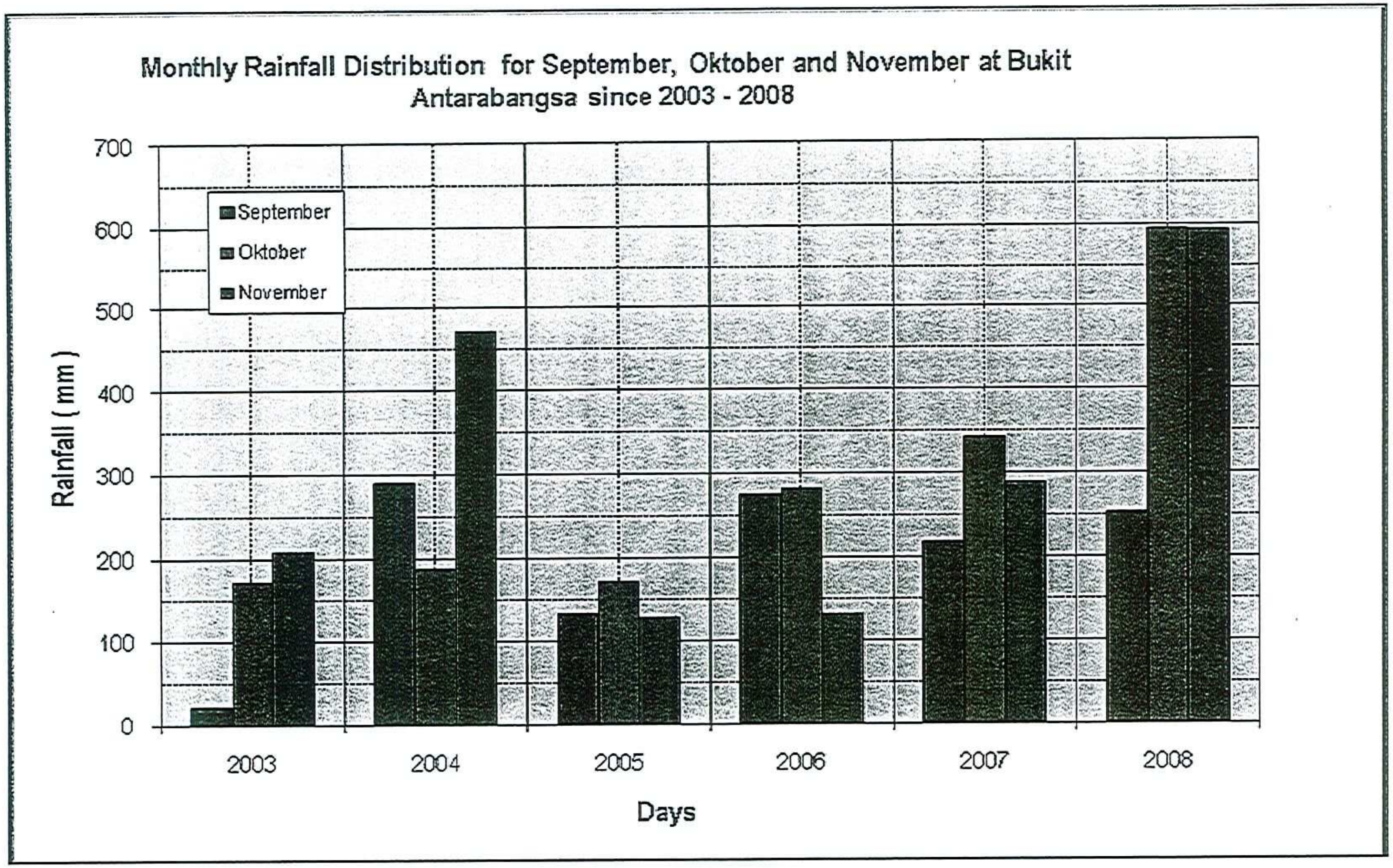

Figure 12: Monthly rainfall records for the September, October and November 2008

Duration	Rainfall Depth in mm for various return periods					
	2 yrs	**5 yrs**	**10 yrs**	**25 yrs**	**50 yrs**	**100 yrs**
1 day	108.4	133.2	149.7	185.9	185.9	201.3
3 day	151.7	189.8	215.1	270.8	270.8	294.4
4 day	167.8	206.3	231.8	288.0	288.0	311.8
5 day	184.9	225.0	251.5	309.9	309.9	334.7
6 day	202.2	247.1	276.9	342.4	342.4	370.2
7 day	218.9	263.5	293.1	358.1	358.1	385.8
14 day	310.3	379.7	425.8	527.3	527.3	570.3
30 day	477.2	566.9	626.5	757.6	757.6	813.2

Table 2: Results of Gumbel Type 1 distribution for annual maximum rainfall recorded at JPS Ampang. (1953-2007)

Based on the frequency distribution of annual maximum rainfalls for the various duration using Gumbel Type 1, the results of the table average recurrence interval of return period are shown in **Table 3**:

Rainfall Durations (days)	Rainfall Depth Prior to Failure (mm)	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

Note: * The ARI is based on IDF JPS Ampang (1953-2007)

Table 3: Average return period for rainfall depth prior to failure at Bukit Antarabangsa

For detailed rainfall analysis, refer to the report entitled "**Analysis of Rainfall for the Taman Bukit Mewah at Bukit Antarabangsa, Selangor for Landslide Tragedy on 6th December 2008**" by JPS.

7.6 Available Topographical/LiDAR Data (Before Landslide)

Topographical information was made available from the Ulu Klang Ampang Hazard Assessment Study project. The topographical information was collected in September 2007 using LiDAR (Light Detection and Ranging). The topographical information was used to generate the slope sections for analysis of stability condition before failure. Orthto-rectified photographs were also made available from the Ulu Klang Ampang Hazard Assessment Study.

7.7 Geotechnical and Geomorphological Data (Before Landslide)

During the Ulu Klang Ampang Hazard Assessment Study, detailed geomorphological mapping works was carried out on the 29th -30th January 2008. Based on the geomorphological map produced, it is clear that the drainage system on the slope between the abandoned houses was in bad condition. Arcuate and alligator cracks were found on the road shoulder of Jalan Wangsa 9. Depression was also observed on the road shoulder above the slope. Gullies were found on the slope below the abandoned houses. Several failure scars were also noted on the slope.

From the geomorphological map produced from the Ulu Klang Ampang Hazard Assessment Study, it is clear that the soil at the landslide location was creeping and showing signs of instability. **Figures 13a** to **13c** show signs of soil creep before the landslide incident.

The signs of distress had also been reported in the geotechnical design report dated 2006 prepared by Messrs. G&P Geotechnics Sdn Bhd.

The geomorphological map and data from the Ulu Klang Ampang Hazard Assessment Study are shown in **Appendix A**.

7.8 Eyewitness Account (Before & After the Landslide)

A total number of twenty-one (21) eyewitnesses were called for an interview with CKC-JKR. This was carried out to obtain information with regards to the history of the site and also accounts of the events leading to the landslide. A short summary of the eyewitnesses accounts is attached in **Appendix B**. A full detailed report on this portion of the report can be read from the report listed in **Section 6.2(d)** prepared by CKC-JKR.

Figure 13a:

Trees leaning on the slope

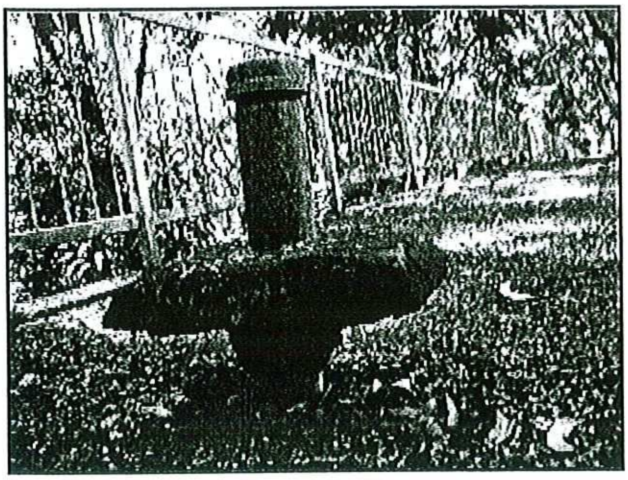

Figure 13b:

Signs of settlement and creep at the crest of the slope

Figure 13c:

Shallow slips were noted at the toe of the slope before failure.

Figure 13: Photographs showing signs of distress and creep before failure (photographs were taken in early 2008 during the Ulu Klang Ampang Hazard Assessment Study)

8.0 PROPOSED SITE INVESTIGATION

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

8.1 Surface Investigation

The surface investigation consisted of:-

a) Topographical & Terrestrial LiDAR survey (TLS)

b) Aerial Photo survey

c) Geomorphological and Geological mapping

d) Test pit, surface infiltration test and soil sampling

8.1.1 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. TLS is adopted to complement the ground survey works. TLS offers the advantage typical of non-contact techniques, permitting collection of dense 3D point clouds over the landslide area in a short period of time. It also records a perspective image and does not require deployment of reflectors. Unstable areas, especially at the failure scar, can be easily and accurately be mapped with TLS without having to worry over the safety of surveyors. **Figure 14** shows a 3D terrain model produced from TLS.

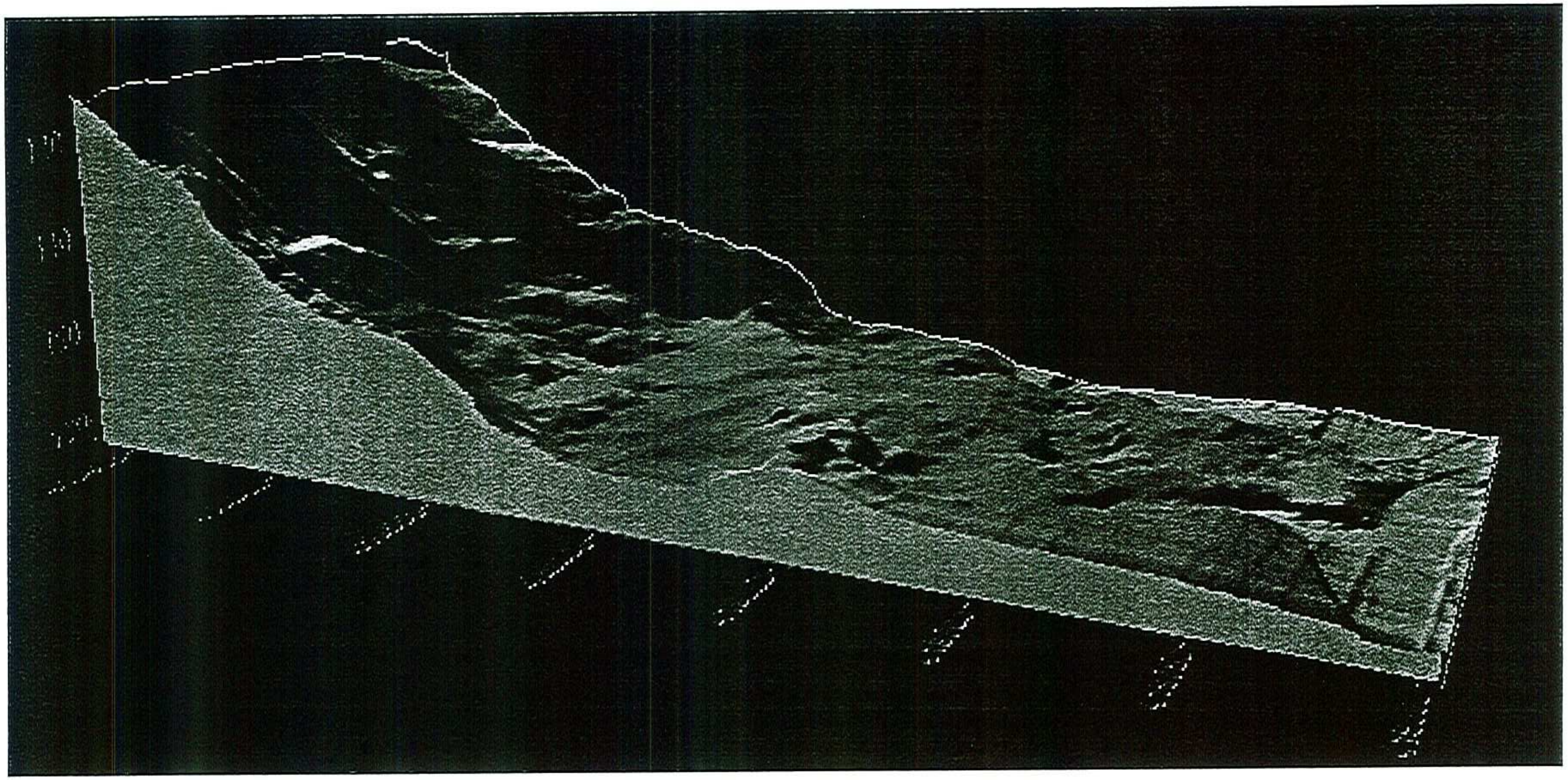

Figure 14: 3D Terrain Model produced from Terrestrial LiDAR Survey (TLS)

8.1.2 Mapping of Drainage and Utility Network

The mapping of drainage and utility network is essential as the failure of any facilities such as reservoirs, water supply and sewerage pipes, drains or sumps may be the major contributing factor to the landslide. There is also a need to evaluate the adequacy of the drainage facilities provided and whether the breakdown of any of these facilities is associated to the landslide. The mapping was undertaken by IKRAM. From the drainage network mapped, the affected slope was equipped with berm drains on slope and roadside drains at the crest of the slope. However, the condition of these drains before the failure was poor, as evidenced from the Ulu Klang Ampang Hazard Assessment Study. Berm drains were found broken and blocked.

From the water reticulation plan, it was understood that there was an active asbestos cement (AC) water pipe of 215mm in diameter running across the slope into the abandoned houses. The damaged water pipe can be clearly seen on the failure scar (refer **Photo 13** in **Appendix C**).

From the sewer plan provided by MPAJ, a sewer pipe was found in front of the abandoned houses connecting the manhole along Jalan Wangsa 11. However, the sewer pipe along the abandoned house was not an active sewer pipe.

Please refer to **Appendix D** for the detailed drainage, water reticulation and sewer plans.

8.1.3 Geomorphological & Geological Mapping

8.1.3.1 Geomorphological Mapping

A team of geologists and geotechnical engineers carried out the geological and geomorphological mapping works. The observations are as follows:

a) Along Jalan Wangsa 9 at the crest of the landslide, a 40m deep headscarp with gradient approximately 45° to 70° was observed. Arcuate cracking was also observed along the longitudinal direction of the road, underneath the temporary protective plastic sheets (refer to **Plate 1**: **Photo 1** in **Appendix C**)

b) The failure side scarp on the northern side of the slope was found to be the deepest among all the side scarps that had been formed by the landslide; measuring up to 20m in depth with gradient ranging from 30° to 50° (see **Plate 2**: **Photo 3** in **Appendix C**). The photo also shows that the abandoned houses were close to the scarp line. Many tree roots were exposed; trees tumbled down due to the landslide. Water pipes of 215mm in diameter and sewerage pipes were also exposed. The berm drains near the abandoned houses were found broken, and water seepage was observed.

c) Near the abandoned houses, the failure exposed a damaged water pipe of 215mm in diameter and sewerage pipes. (Refer to **Plates 3** and **4**: **Photos 13** and **14** in **Appendix C**). These exposed pipes were located underneath the nearby abandoned houses.

d) Crib wall elements were found within the failure debris, and it is believed that the crib wall structures were left in the filled slope of the abandoned development (refer to **Plate 5**: **Photo 12** in **Appendix C**).

e) Broken timber piles were discovered in the failure debris. These foundations remnants are believed to have been left within the filled slope of the abandoned development (refer **Plate 6**: **Photo 7** in **Appendix C**).

f) Generally, the failure debris was observed to be saturated with water. Water ponding at several places within the landslide scar was also noted during the mapping works.

g) Jalan Bukit Antarabangsa at the toe of the landslide had heaved up more than 1 meter above its original level. Jalan Bukit Mewah also heaved up due to the landslide impact (refer to **Plate 7**: **Plate 18** in JMG's Report).

h) Houses at the toe of the landslide were completely damaged. Some units were found to have been swept away by the failure debris.

i) The maximum distance of travel of the failure debris was measured to be approximately 210m from the toe of the landslide.

j) A mixture of soil and rock boulders was noted on the failure scar located at the northern corner of the slope toe. This is believed to be dumped or spoiled materials during the development.

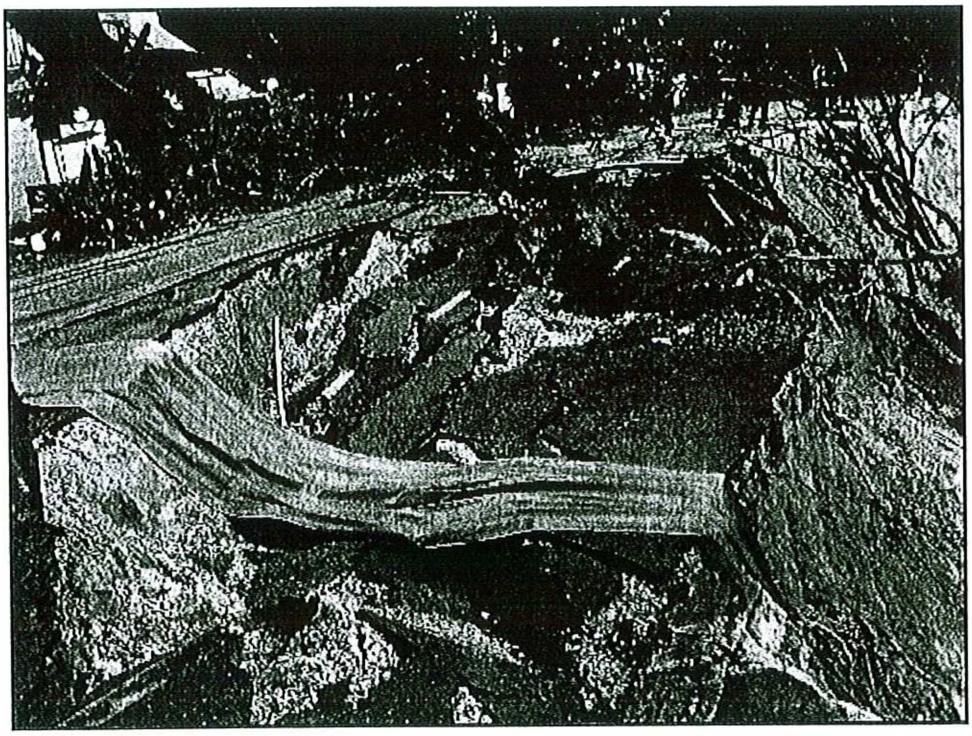

Plate 1 (**Photo 1** in **Appendix C**)

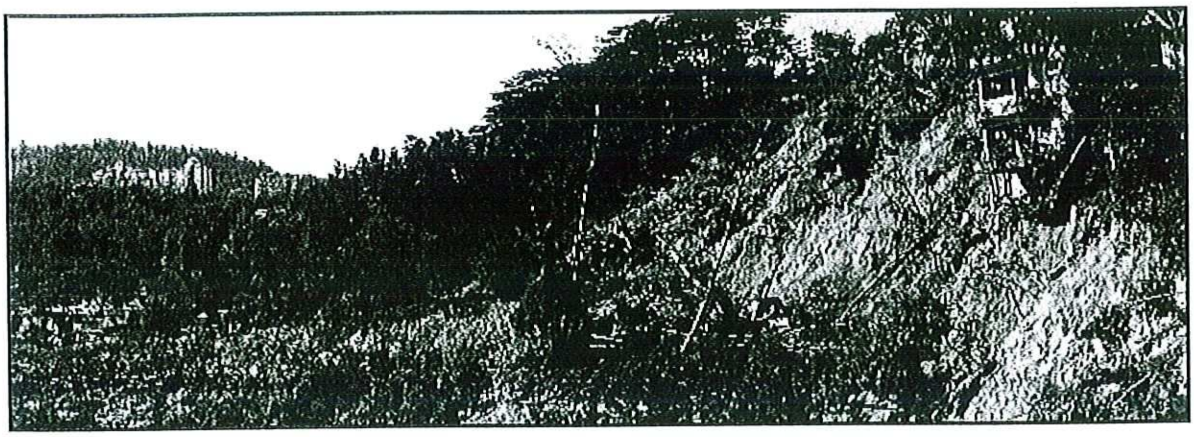

Plate 2 (**Photo 3** in **Appendix C**)

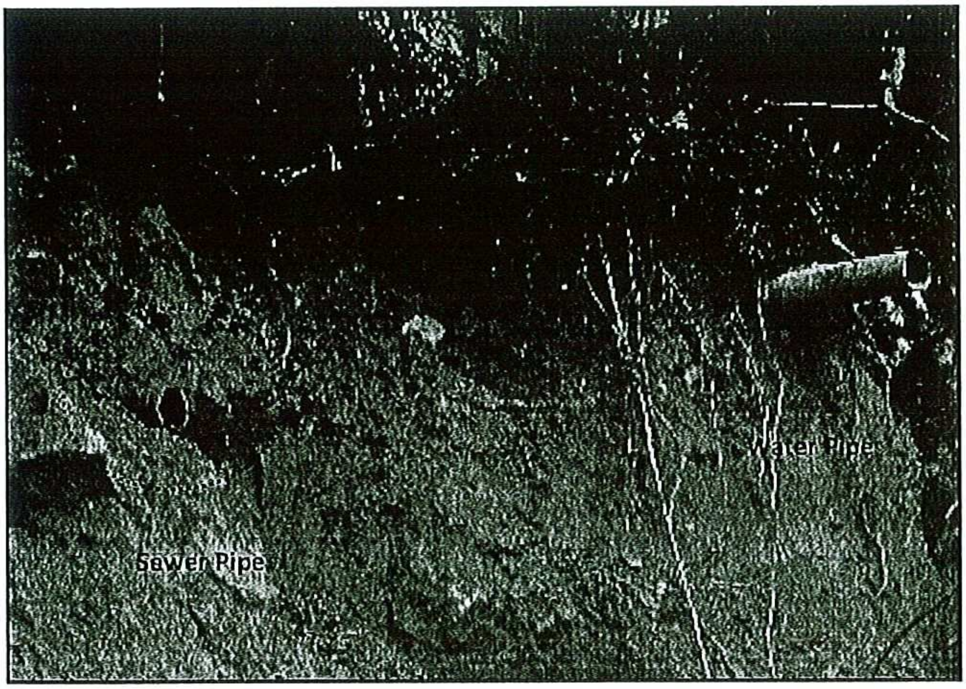

Plate 3 (**Photo 13** in **Appendix C**)

Plate 4 (**Photo 14** in **Appendix C**)

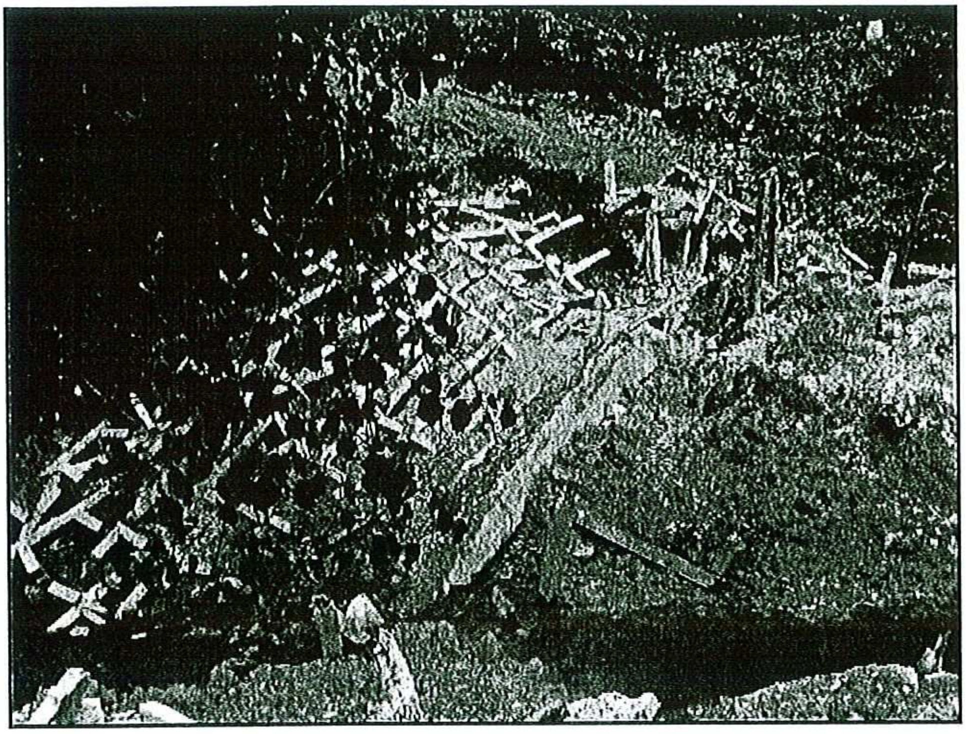

Plate 5 (**Photo 12** in **Appendix C**)

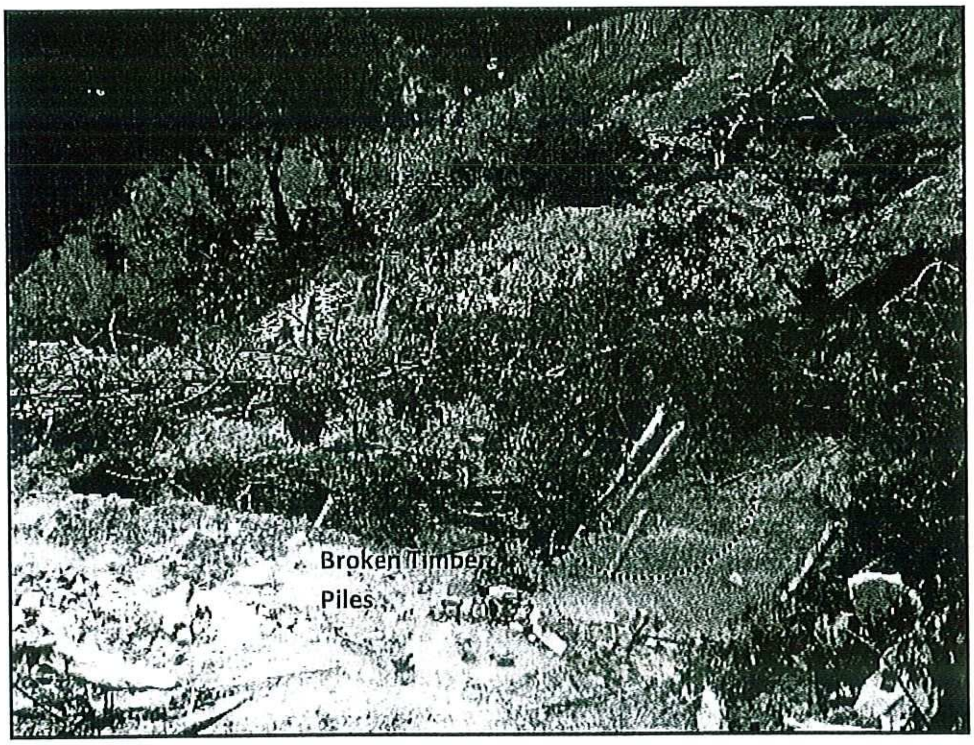

Plate 6 (**Photo 7** in **Appendix C**)

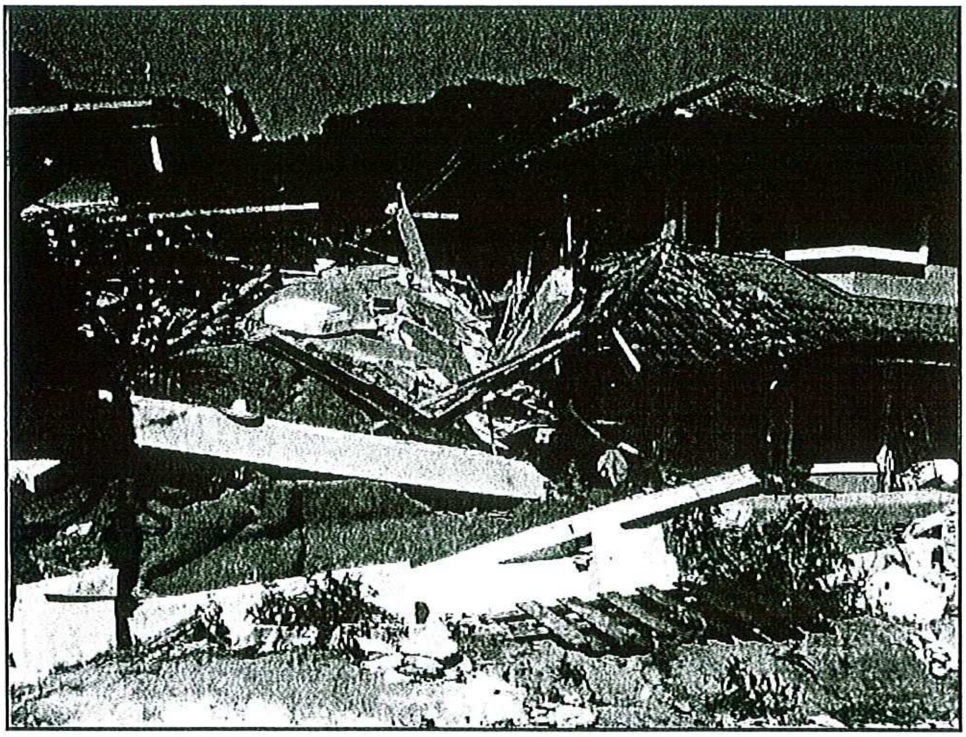

Plate 7 (**Plate 18** in **JMG's Report**)

Figure 15 shows the geomorphological map of the landslide area. Photographs taken during the geomorphological mapping works are attached in **Appendix C**.

A detailed geological mapping has also been carried out by JMG after the failure and is attached in **Appendix E**.

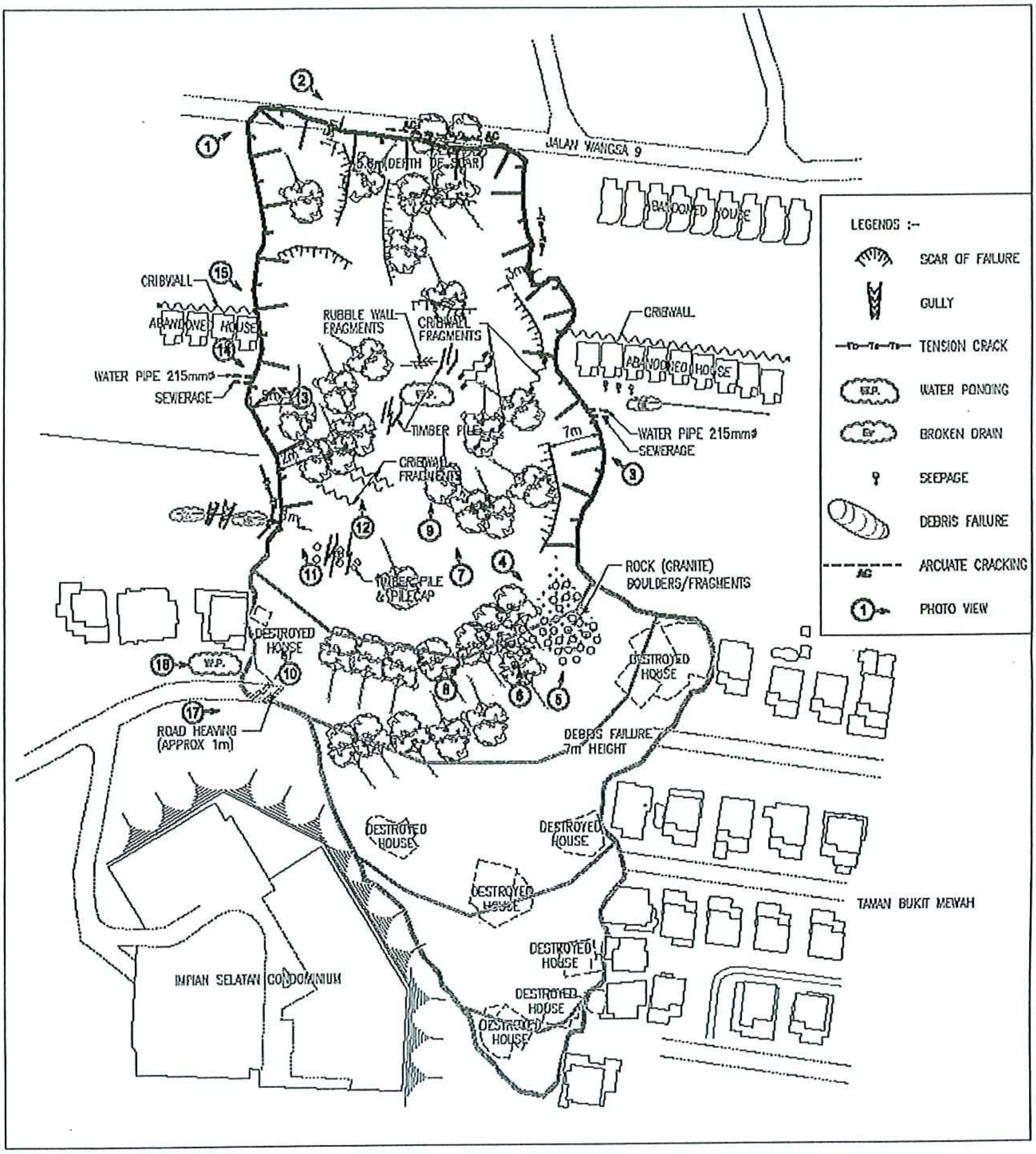

Figure 15: Geomorphological map of the landslide area

8.1.4 Test Pits & Soil Samplings

Initially, two (2) test pits were planned near the crest of the failure during the subsurface investigations. However, as the proposed test pits were located very close to the crest of the landslide scar, it was dangerous to carry them out. Hence, the test pits were omitted to avoid further deterioration of the failure scar or any unwanted incidences.

Six (6) locations were selected to perform the surface infiltration tests to measure the in-situ infiltration rate of the soil (refer to **Figure 16**). Two (2) tests were assigned in each location. The double ring method was adopted to perform the tests (refer **Figure 17**).

Table 4 shows the summary of the surface infiltration test. In general, the infiltration rates obtained for these locations are high, ranging from $1x10^{-5}m/s$ to $5x10^{-5}m/s$.

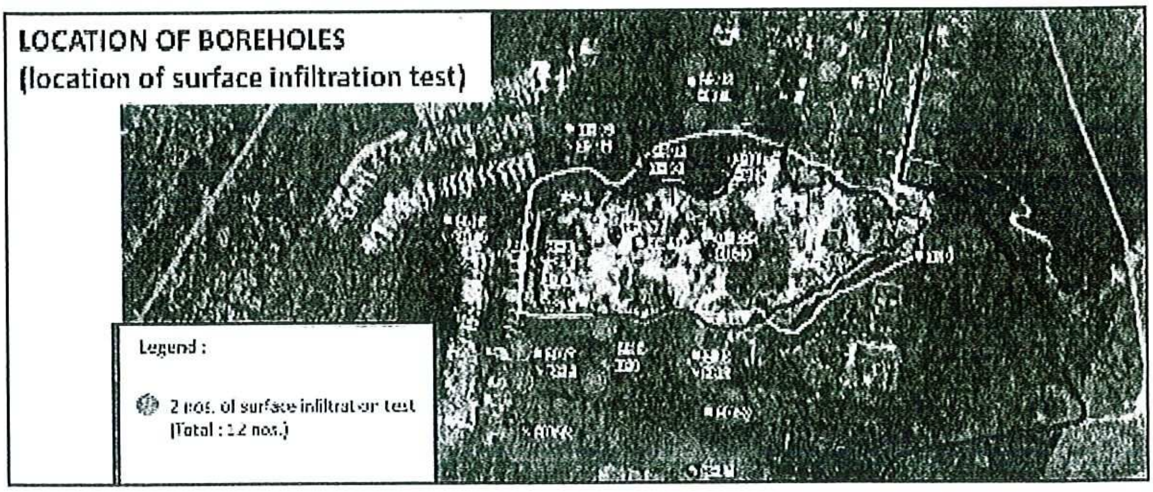

Figure 16: Location of infiltration tests

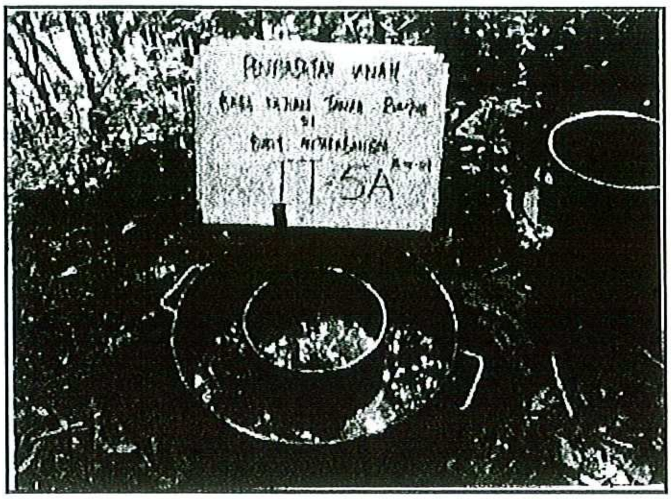

Figure 17: Double ring method

Location No.	Test No.	Infiltration rate (m/s)	Soil description based on Laboratory Test
1	IT-4A IT-4B	0.00 (error) 1.0E-05	Very clayey SAND with trace of gravel
2	IT-4A IT-4B	5.0E-05 1.0E-05	Sandy SILT with trace of gravels
3	IT-4A IT-4B	3.0E-05 4.0E-05	Very Silty SAND with trace of gravels
4	IT-4A IT-4B	1.0E-05 1.0E-05	Sandy SILT with trace of gravels
5	IT-4A IT-4B	4.0E-05 3.0E-05	Very silty SAND
6	IT-4A IT-4B	4.0E-06 3.0E-06	Well-graded SAND with trace of gravels

Table 4: Summary of infiltration test results

8.2 Subsurface Investigation (SI) Works

8.2.1 Boreholes

A total of twenty five (25) borehole investigations, i.e. BH1 to BH25, 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 (19 nos.) to retrieve appropriate samples for the laboratory testing, as wash boring method was not advisable.

The depth of the boreholes from the existing ground surface ranges between 7.00m to 52.69m below ground level (b.g.l). In-situ tests such as Standard Penetration Test (SPT) were carried out in each borehole at every 1.5m intervals. In general, boreholes are terminated after a minimum of five (5) consecutive SPT-N value of greater than 50 blows/300mm or after 3m of solid rock coring. In this case, most boreholes were terminated after encountering five (5) SPT-N value of 50.

Instrumentation monitoring was carried at for 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. The locations of the proposed boreholes and instrumentation as well as the bore logs are shown in **Appendix F. Table 5** shows a summary of the boreholes and the investigation monitoring carried out.

Borehole No.	Depth of boreholes (m bgl)	Instrumentation Type Installed
BH1	21.80	Piezometer
BH2	19.60	Inclinometer
BH3	12.00	Piezometer
BH4	28.70	Inclinometer
BH5	21.00	Piezometer
BH6	25.87	Inclinometer
BH7	18.00	Piezometer
BH8	32.30	Inclinometer
BH9	27.20	Piezometer
BH10	7.00	Piezometer
BH11	8.60	Piezometer
BH12	19.50	Inclinometer
BH13	19.50	Piezometer
BH14	31.40	Inclinometer
BH15	21.00	Piezometer
BH16	27.80	Inclinometer
BH17	22.70	- Nil -
BH18	23.40	Inclinometer
BH19	20.30	Piezometer
BH20	36.30	Piezometer
BH21	52.69	Inclinometer
BH22	28.50	Inclinometer
BH23	34.50	Piezometer
BH24	43.30	Piezometer
BH25	20.40	Piezometer

Note: mbgl denotes meter below ground level

Table 5: Summary of boreholes and the investigation monitoring carried out

The wash boring technique was used in only six (6) of the boreholes to install additional piezometers for water level monitoring purposes. Continuous samplings were also carried at some borehole locations for soil material logging (cut or fill material) in the laboratory.

Tables 6a and **6b** show the summary of the continuous sampling carried out on three (3) boreholes, i.e., BH 5, 9 and 17, located near the failure area while **Appendix G** shows the pictures taken when each sample was extracted. Based on the continuous sampling, it can be clearly seen that the top soil at the abandoned house area consisted of loose fill.

Borehole	Sample	Depth (m)	Description
BH5 (Left Hand Side Of Failure-looking upwards) (Near Abandoned House)	UD1	2.0	Various layers Broken vases Backfill material
	UD2,UD3	4.0	Various layers found Traces of fresh granitic rock (fragment) Backfill material
	UD4	5.0	Various layers of SAND and SILT found Backfill material
	UD5,UD6	7.0	Traces of decayed wood and plants found Backfill material
	UD7,UD8	10.5	Decayed wood Backfill material
	UD9,UD10	13.0	Decayed plant and wood found Backfill material
	MZ2	19.0	Various layers found Weathered granite. Deeper than this may lead to boulders and eventually original ground.

Table 6a: Summary of continuous sampling

Borehole	Sample	Depth (m)	Description
BH9 (Crest Of Failure)	UD1, UD2	2.5	Traces of fresh granite (rock fragments) found
	UD3, UD4,	5.68	Traces of quartz gravels found
BH17 (Right Hand Side Of Failure-looking upwards) (Near Bukit Mewah)	UD1,UD2	3.0	Various layers found Traces of fine quartz gravel found with decayed wood and organic matter
	MZ1,MZ2, MZ3,MZ4, MZ5	19.0	Various layers Trace of quartz gravels found with decayed wood and plants Traces of construction material (reinforcement bars) found Broken vases found

Table 6b: Summary of continuous sampling

8.2.2 Subsoil Profile at the Landslide Area

Based on the subsurface investigation report and the borehole investigation, the subsoil profile of the site can be summarized as tabulated in **Tables 7** and **8** (refer to **Appendix H** for five (5) cross-sections showing the subsoil profile of this area):

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 7: Subsoil profile (failure scar 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)

Table 8: Subsoil profile ((left hand side) and (right hand side) of failure area)

8.2.3 Groundwater Monitoring

Groundwater 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. **Table 9** below shows the maximum height of water level recorded and its date (over the period of December/January 2008 to 24th February 2009).

BH	Piezometer (SP)	Date Taken	Highest Water Level Recorded (mbgl)	Groundwater Level Range (mbgl)
BH1	SP1	05/01/2009	1.47	1.470 to 1.910
BH3	SP3	07/01/2009	1.77	1.770 to 2.340
BH5	SP5	10/01/2009	13.42	13.420 to 15.220
BH7	SP7	14/01/2009	NIL	NIL
BH9	SP9	31/12/2008	26.40	26.400 to NIL
BH10	SP10	05/01/2009	3.53	3.530 to 4.680
BH11	SP11	16/01/2009	6.52	6.520 to 8.700
BH13	SP13	05/01/2009	17.36	17.360 to 17.410
BH15	SP15	14/01/2009	15.92	15.920 to 18.110
BH17	SP17	22/01/2009	0.54	0.540 to 0.950
BH19	SP19	12/01/2009	13.61	13.610 to 16.320
BH20	SP20	07/01/2009	5.59	5.590 to 6.230
BH23	SP23	16/01/2009	5.68	5.680 to 6.000
BH24	SP24	16/01/2009	12.52	12.520 to 13.210
BH25	SP25	14/01/2009	1.98	1.980 to 3.600

Note: mbgl denotes meter below ground level

Table 9: Summary of highest recorded piezometer levels (over the period December/January 2008 to 24th February 2009)

Refer to **Appendix I** for the three (3) cross-sections drawn out to identify with the subsoil profiles and the maximum piezometer profile. Upon the installation of the piezometer, it was observed that the groundwater dropped 1 to 3m below its highest recorded level, and ever since, has stabilized. This entire motion took two (2) to three (3) weeks to reach its stable state.

Meanwhile, **Appendix J** shows two (2) cross-sections and how the inclinometer instrumentation readings detecting the lateral movement of the slope after the landslide. Based on the settlement records, the settlement at the top of the inclinometers (at shallower depth) is more evident. As the depth increases, the settlement is negligible. The settlement at the shallower depth also seems to have stabilized after some time (within seven (7) to twelve (12) days) after the landslide. More readings on this can be obtained from the information listed in **Section 5.2 (b) Volume III** prepared by Kumpulan IKRAM Sdn Bhd.

8.2.4 Geophysical Investigation

A geophysical investigation was conducted by JMG upon the failure occurrence. 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.

Minerals and Geoscience Department Malaysia-JMG's Geology Report is referred to in this context of the report. Based on the write-up, the Resistivity Line 1 (along Jalan Wangsa 9 - refer to **Appendix K** for Resistivity Profile Line 1) shows that there is a presence of highly weathered, fractured and saturated granitic bedrock ranging between 5 to 45m. This justifies the continuous sampling results and the borehole investigation on BH10 and BH11 that shows rock coring with average RQD of 50%.

Resistivity Line 10 (see **Appendix L**) shows that the fill material at the abandoned houses is at least 10m thick. This result can be supported by rechecking the SPT-N values obtained based on boreholes BH6 and BH12 located on the left and right hand side (looking upwards) in between the landslide scar. Up to the depth of 15m, both boreholes display variation of layers (silt, sand and clay) with SPT-N 1 to 10.

Resistivity Line 6 (see **Appendix M**) which represents the profile area along Jalan Wangsa 11 shows that there are pockets of saturated sandy material towards the right side (looking upwards) of the failure scar. Checking with BH18, granitic bedrock is only found at 13m below the ground surface. Based on the eyewitness report by Captain Hassan, it was mentioned that the sump between Jalan Wangsa 5 and Jalan Wangsa 9 broke, and this may have caused the heavy infiltration of water into the ground below. That justifies the water pockets discovered in the resistivity tests. Refer to **Appendix M** for the other resistivity lines study that were carried out by JMG.

8.3 Geotechnical Interpretation

The disturbed soil samples retrieved during the foam drilling were taken to the laboratory for testing. 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.

8.3.1 Physical Soil Properties

The Atterberg Limits Test of the soil samples collected from the boreholes gives the liquid limit (LL) and Plasticity Index (PI) of the samples. The top soil of the subsoil profile surrounding the failure area, i.e., the fill layer, indicates Liquid Limit (LL) of 32 to 69%, Plastic Limit (PL) of 19 to 37%, and Plasticity Index is 6 to 42. The layer generally consists of intermediate plasticity. Meanwhile, the classification test conducted on the failure area gave a top soil with Liquid Limit (LL) of 32% to 52% and Plasticity Index of 12 to 29. Here again the layer is generally intermediate plasticity. The plasticity charts for all the samples tested can be referred to in **Appendix N**.

8.3.2 Shear Strength Properties

The undisturbed samples collected were tested using the Consolidated Isotropic Undrained Triaxial (CIU) to attain the shear strength parameters. Based on the results, the T-S plot was sketched out and the effective cohesion (c') and friction angles (φ') were obtained. The following **Table 10** shows the shear strength parameters obtained based on the laboratory test. The CIU Plot can be referred to in **Appendix P**.

Parameters Taken	**Effective Cohesion, c' (kPa)**	**Friction Angle, φ' (°)**
Lower Bound	4	29
Upper Bound	13.7	33

Table 10: Shear strength parameters

8.3.3 Other Soil and Rock Properties

The moisture content of the samples extruded from the boreholes were plotted against their respective depths (refer **Appendix Q**). In general, the moisture content within the failure and its surrounding areas is between 10 to 27%.

The rock (granite) cores collected from the boreholes were tested in the laboratory, using the Unconfined Compressive Test (UCT) to obtain the strength of the rock core. The UCT values range from 25 MPa to 40 MPa (for shallow rock area) and up to 60 MPa for deeper depth rock core. According to Hoek and Brown (1997), these UCT values indicate that the rock is medium strong. Refer to **Appendix R** for the UCT plot against depth.

9.0 MODE AND MECHANISM OF FAILURE

Based on the letter submitted by JMM (refer to **Appendix B**), the seismic records show that there was no signs of earthquake motion on the day of the landslide, i.e., 6th December 2008, and also a month before that. This eliminates the probable cause of failure due to earthquake.

From the eyewitness account by one of the residents, during the landslide, the affected 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 indicates that the debris was "fluid-like".

The buried water pipe exposed at the failure scar near the abandoned houses was reported to be an active water pipe (confirmed by SYABAS personnel during the eyewitness interview). Rapid water flow in the drain along Jalan Wangsa 11 was reported by one of the eyewitnesses, around 1.39 a.m. on 6th December 2008 even though no rain was reported on the previous day. SYABAS was informed and managed 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, and the water ceased to flow in the drain. From the eyewitness account with the SYABAS technician, it was mentioned that a water source was found flowing from the direction of abandoned houses (at the mid level of the failed slope) towards the roadside drains in Jalan Wangsa 11.

From the mapping works carried out and the aerial photographs taken before and after failure, Jalan Bukit Antarabangsa was found to have heaved, and a few bungalows were displaced away from their original positions. The slide was indicated to be deep-seated, where the sliding plane went below the road and the founding level of the first row of the bungalows (see **Figure 18**).

The cross-sections extracted from TLS indicate that at least three (3) slumps were involved in the landslide (see **Figure 18**). 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 eyewitness accounts, the first loud crash resulted in the displacement of the houses to the main road (Jalan Bukit Antarabangsa). The second and third crashes (the second and third slumps) resulted in the debris and houses to be displaced further.

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, Dr M.A. et al, 2001).

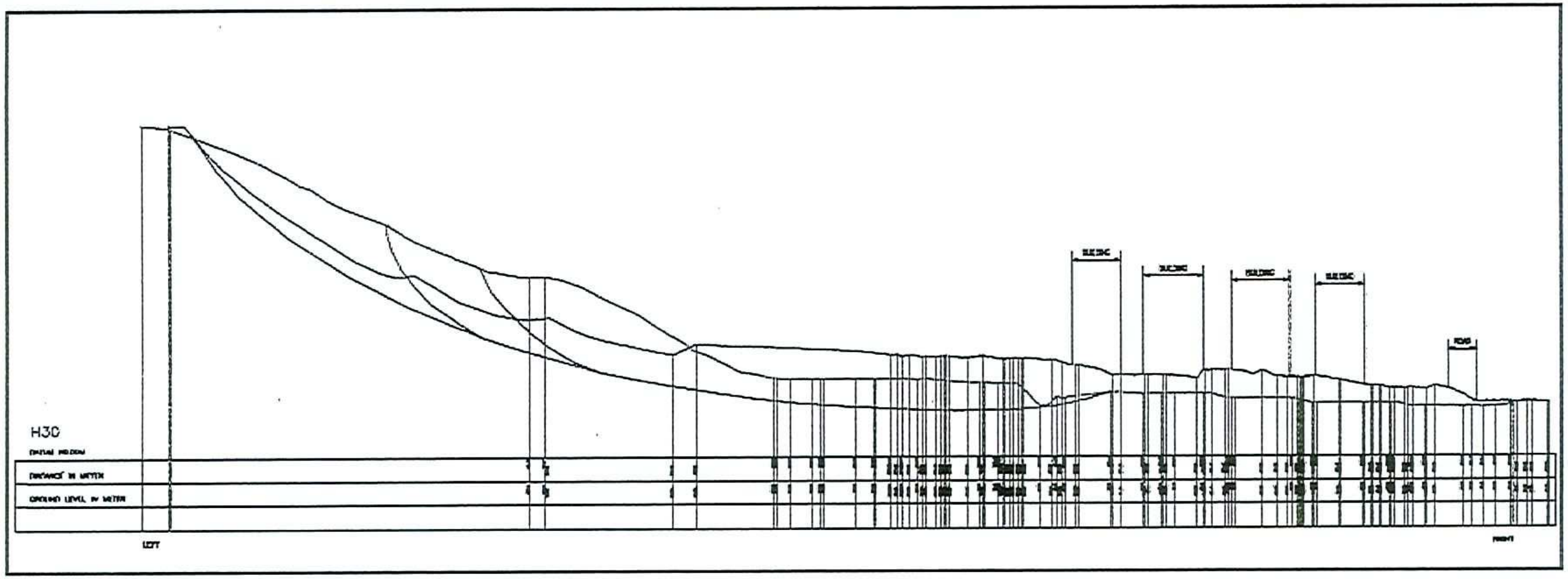

Figure 18: Cross section extracted from TLS and LIDAR showing the 3 (three) slumps

10.0 BACK ANALYSIS TO SIMULATE FAILURE

10.1 Geotechnical Model

From the boreholes investigations, it was found that the soils were believed to be dumped/spoiled earth without proper compaction. BH12 and BH 22 located at the top row of the abandoned houses show that the soil consists mainly of Silty SAND with varying consistency from very loose to very dense. From BH12, very loose material with SPT =0 to 2 was found at the depth of 5m and 7.50m below ground level (refer to the borehole logs **Appendix F**). Rock boulders were also detected within the filled layer. These were probably remnants of earth dumping as evidenced from the aerial photograph taken in 1975 by JUPEM.

Table 10 shows the range of the soil shear strength parameters obtained from the laboratory CIU tests. The shear strength parameters in **Table 10** do not represent the shear strength of the soils at the failure site. This is based on the boreholes where there were loose lenses found below the ground surface. Therefore, no samples of the loose lenses were retrieved during the investigations. The shear strength parameters in **Table 10** are considered to be relatively high, and would not represent the actual values. 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 **$\phi' = 25°$ to $28°$.**

For the stability analysis, the soil shear strength parameters adopted are $\phi' = 26°$ and cohesion $c' = 3$kPa.

10.2 Failure Plane

The estimation of the failure plane is based on the findings of the geomorphological mapping works and cross section extracted from TLS works. This is shown in **Figure 18.** The green line indicates the original ground profile before the failure. The blue lines show the three (3) slumps formed which 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) is 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. The red line in the figure indicates the profile after the landslide.

10.3 Pore Water Pressure at Failure

The pore water pressure in the slope at failure is difficult to predict. The SI works that were carried out would only be able to provide the hydrostatic/ phreatic level of the area based on the piezometer monitorings. Using these hydrostatic levels, the global stability of the area will be assessed; however, this does not reflect the actual event that took place. To determine the pore water pressure conditions at failure, firstly, the interpreted geotechnical model and failure geometry as described in the previous Sections 10.1 and 10.2 is adopted. And secondly, using stability analysis, the pore water pressure ratio, Ru (Ru is a coefficient that relates the pore water pressure to the overburden stress) values of 0.1 to 0.4 are applied to obtain its respective Factor of Safety (FOS) values. The next section will explain in detail, the findings of the stability analyses carried out.

10.4 Stability Analysis

A total of five (5) cross-sections were simulated in the stability analysis using SLOPE/W 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., **H30**, **H45** and **H60**, while the other two (2) cross-sections were at the left and right sides (looking upwards) of the failure area, i.e., **Sections 2-2** and **3-3** (see **Appendix S** for the locations of these cross-sections).

10.4.1 Using Phreatic Level

The stability analyses were carried out for two (2) conditions. The first condition uses the hydrostatic/ phreatic levels based on the highest recorded piezometer monitorings to obtain the global stability FOS values. The detailed analyses are shown in **Appendix T**. The results of the analysis are summarized in **Table 11**. The second condition uses the pore water pressure (Ru) coefficients. The detailed information is summarized in **Item 10.4.2**.

From the global analyses carried out, the safety factors obtained were found to be greater than 1 but very marginal at the failure area. Therefore, for a failure to occur in the current landslide area, the ground water level for the area could have been much higher during the actual incident. This analysis does not show the state of the pore water pressure during the failure. This analysis does not reflect the actual event that had taken place.

Cross Section	Factor of Safety (FOS)
<u>At Failure Area</u>	
i) H30	1.237
ii) H45	1.081
ii) H60	1.179
Sec 2-2 (LHS)	1.157
Sec 3-3 (RHS)	1.313

Table 11: Factor of Safety (FOS) based on Hydrostatic Phreatic Levels

10.4.2 Using Pore Water Pressure (Ru) Coefficients

The findings during the geomorphological mapping points 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 toe slope.

Therefore, in this parametric study 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).

The pore water pressure ratios (Ru) of 0.10, 0.20, 0.25, 0.30 and 0.40 were applied in the analyses to obtain the Factor of Safety (FOS) at the toe of the slope (first slump). The detailed analyses are shown in **Appendix T.** The results of the analysis are summarized in **Table 12.**

From the analysis, a failure is likely to occur when the FOS is close to or less than one (1.0). Based on section H30 and H60, the Ru at failure is likely to range from 0.25 to 0.30. Meanwhile, section H45 the Ru at failure ranges from 0.20 to 0.25 (refer to **Figure 19**).

Ru coefficients	**Factor of Safety (FOS)**		
	Section H30	**Section H45**	**Section H60**
0.10	1.260	1.180	1.293
0.20	1.109	1.038	1.138
0.25	1.034	0.968	1.061
0.30	0.960	0.898	0.985
0.40	0.815	0.762	0.833

Table 12: Factor of Safety (FOS) based on Pore Water Pressure Ratios

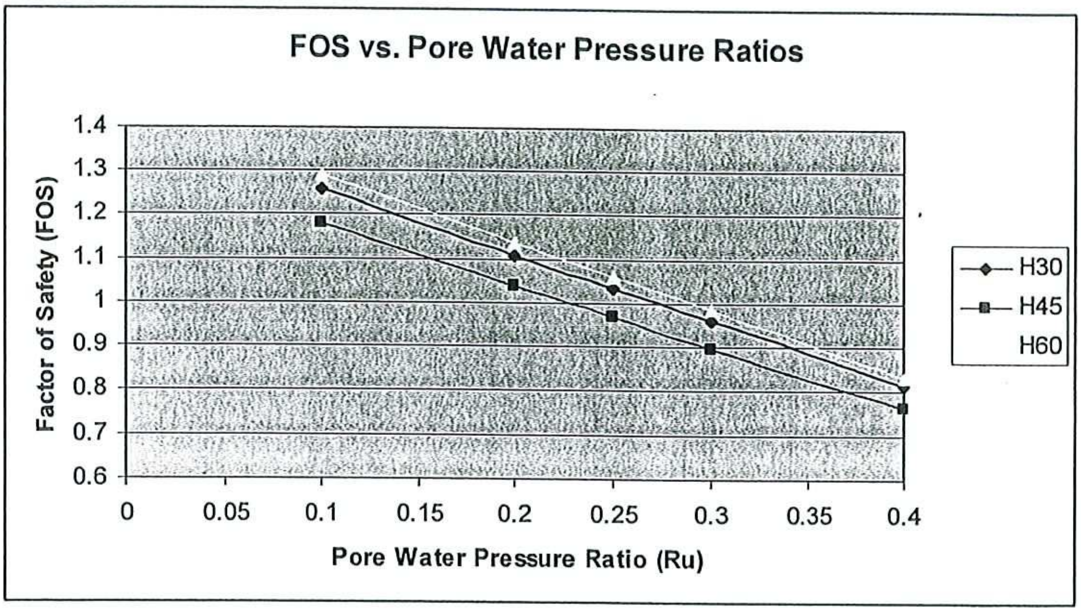

Figure 19: Factor of Safety (FOS) based on Pore Water Pressure Ratios

Another series of analyses were carried out based on the section H45 as this cross-section passes through in the middle of the failure area (see **Appendix S**). The pore water pressure ratios (Ru) of 0.10, 0.20, 0.25, 0.30 and 0.40 were applied in the analyses of section H45 to obtain the Factor of Safety (FOS) at the toe of the slope (first slump) for various soil parameters. The soil parameters for the non-engineered fill with loose lenses were applied in the range of c' = 3 to 4 kPa and φ' = 26° to 29°. The detailed analyses are shown in **Appendix T**. The results of the analysis are summarized in **Table 13.**

Based on various soil parameters, the Ru at failure is likely to range from 0.20 to 0.30 (refer to **Figure 20**).

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.

Ru coefficients	Factor of Safety (FOS)				
	c'=4kPa, φ'=29°	c'=4kPa, φ'=28°	c'=4kPa, φ'=27°	c'=4kPa, φ'=26°	c'=3kPa, φ'=26°
0.10	1.355	1.304	1.253	1.204	1.181
0.20	1.193	1.149	1.105	1.062	1.038
0.25	1.114	1.072	1.031	0.991	0.968
0.30	1.034	0.996	0.958	0.921	0.898
0.40	0.879	0.847	0.816	0.785	0.762

Table 13: Factor of Safety (FOS) for Section H45 based on Pore Water Pressure Ratios for Various Soil Parameters

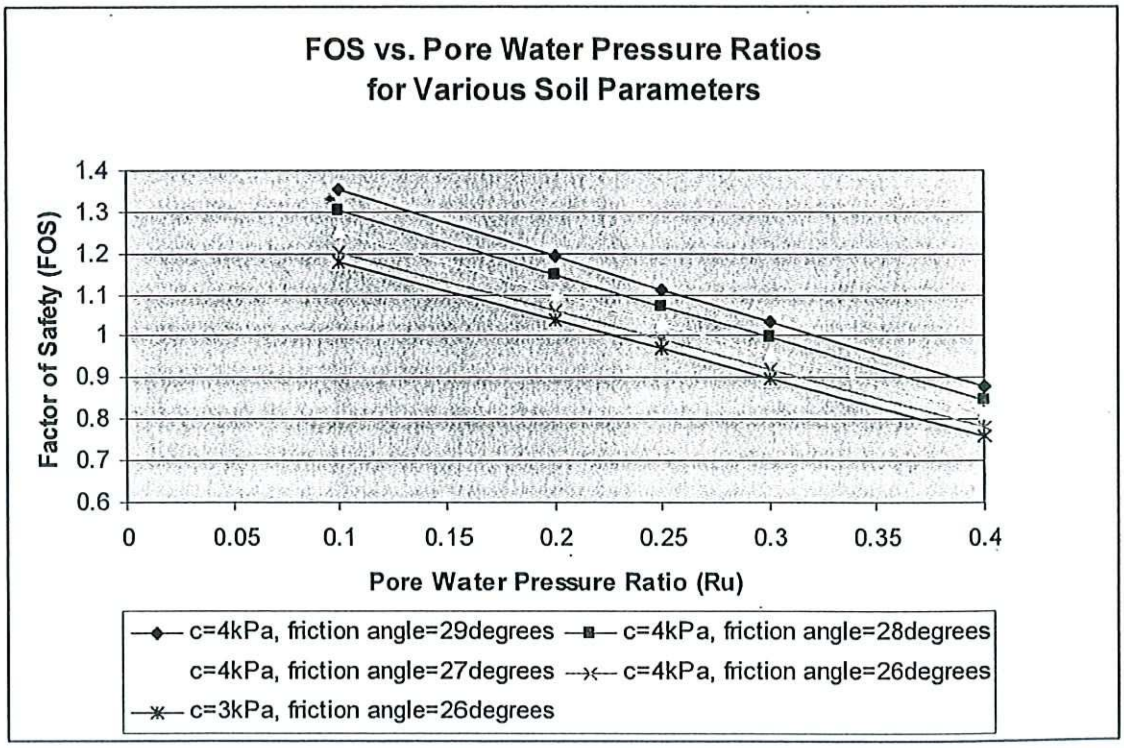

Figure 20: Factor of Safety (FOS) based on Pore Water Pressure Ratios for Various Soil Parameters

11.0 IDENTIFICATION OF FACTORS CONTRIBUTING TO THE FAILURE

There are several causal factors contributing to the landslide. The probable contributing factors are as follows:-

a) Soil creep due to non-engineered fill on the slope.

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) Poorly maintained and damaged drainage system contributed to increased water infiltration into the slope.

d) Loose/non-compacted "dumped earth" with high void ratio placed in the natural valley caused high permeability in soil.

e) Prolonged rainfall during the month of October and November caused soil saturation and rise in ground water table.

f) Increased soil creep further damaged the drainage facilities and widened the existing cracks and opened up new tension cracks.

12.0 SUMMARY AND CONCLUSIONS

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

From the investigation undertaken, the following conclusions can be made:

a) The three (3) slumps were confirmed by the TLS as well the eyewitness accounts of three (3) loud crashing sounds.

b) The ratio of the failure depth to the slope length was found to be greater than 0.1, classifying it as a deep-seated failure. Deep-seated failure is often associated with high pore water pressure.

c) The seismic survey carried out confirmed the existence of pockets of loose sandy material in the soil profile. The resistivity survey carried out identified pockets of saturated fill material overlaying highly weathered and jointed granitic bedrock.

d) Due to the existence of these loose lenses in the non-engineered fill (suspected 'dump' material), the shear strength parameters adopted in the analyses and parametric study were lower than the actual values obtained from the laboratory test results (no sample was recovered from the loose lenses).

e) The sumps at junction of Jalan Wangsa 5 and Jalan Wangsa 9 were found broken, allowing high water infiltration into the ground.

f) From the geomorphological mapping carried out in the Ulu Klang Slope Assessment Study before the landslide incident, the drainage on the failure area was found to be broken and blocked.

g) Based on the rainfall records, exceptional high and prolonged rainfall was recorded for the month of October to November.

h) Active water pipe line running in front of the abandoned house was found to be leaking heavily just before the landslide incident.

From the failure assessment, it is concluded that the landslide has 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) Poorly maintained/ damaged drainage system on the failed slope and its surrounding.

c) Prolonged rainfall during the months of October and November.

d) Prolonged soil creep widened the existing cracks and opened new tension cracks.

e) Heavily leaking active water pipe along abandoned houses due to soil creep.

From the above, the most probable triggering factor of the landslide is due to the water leakage from the active water pipe along the abandoned houses that caused a build-up of high pore water pressure in the slope.

13.0 IMMEDIATE RECOMMENDATIONS

Immediate recommendations to prevent a reoccurrence of the landslide in Bukit Antarabangsa based on this final investigation works are as follows:

a) Efforts must be made to identify areas with similar non-compacted filled/dumped ground.

b) Repair and upgrade damaged and undersized drains within the vicinity of Bukit Antarabangsa.

c) Installing subsoil drains at areas where water seepage and high ground water table are located.

d) Undertaking instrumentation monitoring as early warning system at high risk areas.

e) Undertaking detailed inspection and assessment of slopes with signs of distress. Areas with prolonged soil creep must be regularly inspected and preventive works must be immediately undertaken.

f) All water pipe adjacent to slope shall be exposed.

g) All the water and sewer utilities on slopes shall be inspected periodically for leakage and damage.

h) All hillside development shall follow strictly to the development guidelines by the local authority.

14.0 DISCLAIMER

The findings stipulated in this report are merely based on the available data or information obtained up to the stage of report writing.

15.0 REFERENCES

These following references were made in conjunction with this investigation report write up.

a) Othman, Dr M.A. et al (2001) "Slope Instability Problems of Roads in Mountainous Terrain: A Geotechnical Perspective".

b) Hoek, E and Brown, E.T. "Practical Estimates of Rock Mass Strength", Int. J. Rock Mech. Min. Sci. Vol 34 (1997).

c) Stability Modeling With Slope/ W 2007 (An Engineering Methodology) GEO-SLOPE International Ltd. Second Edition, May 2007.