Massive Creep Movements of Post-Glacial Deposits in Kundasang Areas

S. S. LIEW & S. S. GUE
Gue & Partners Sdn. Bhd., Malaysia

ABSTRACT: This paper presents an interesting case history of a massive creep movement of the post-glacial deposits in Malaysia. Subsurface investigation and instrumentation programmes have been implemented to investigate the causes of such movement. The monitoring results reveal that the rate of ground movement can be as high as 21mm per week.

The engineering assessment using slope stability program to back-analyse the strength parameters of the moving soil masses indicates that the ranges of back-analysed cohesion, C', and the internal friction angle, ϕ', are 0 to 5kPa and 13° to 16° respectively, which are smaller than the laboratory strength results interpreted from the direct shear box tests and consolidated isotropically undrained (C.I.U.) tests.

1.0 INTRODUCTION

The road authority in Sabah has experienced constant pavement repair works for the access road, Jalan Cinta Mata off Jalan Kundasang-Ranau, leading to the Desa Cattle Farm, Kundasang Golf Course and further up to the vegetable farms. The location of the Jalan Cinta Mata is shown in Figure 1. There is about 1.2km stretch of this road, in which the pavement requires repair works every few months. The visible distresses observed on pavement occur in the ways of tension cracking, settling and lateral movements. In view of the frequent recurrence of pavement repair works and the inconveniences of vehicles passing through the distressed stretch of the road, the need to find out the root cause of the problem for permanent solution arises. A comprehensive geotechnical investigation is therefore carried out to study the problem in stages. This paper presents the findings in the preliminary stage of investigation.

2.0 BACKGROUND OF SITE

The affected road alignment generally traverses in north-east direction at the first 600m and changing to south-east direction at the remaining 600m. The road level ascends from RL1335 to RL1500. The overall site terrain is generally undulating in nature as shown in Photo 1.

The surrounding ground surface of the area is featured with many clusters of large granitic boulders. Occasionally, grey shale (from Trusmadi Formation), red/grey shale and sandstone (from Crocker Formation) outcrops can be seemed on the right of Jalan Cinta Mata.

There are a power transmission line running across the cattle farm and a telephone line running along the road alignment. The posts on the sloping ground were tilted due to the ground movements and the tensioning electrical cables was observed holding the top of the posts in place whereas the posts on the higher flatter and stable ground were being pulled at the top becoming tilting posts towards downhill. Photo 2 shows the tilted posts with tensioned cables.

There is an abandoned pump houses (PH-2) at the left hand side after turning into the Jalan Cinta Mata and another pump house (PH-3) at the right hand side near the end of the affected chainage of the road. Photo 3 shows the location of the pump house (PH-2). This pump house is built for the Mesilau Mini Hydro project as part of the irrigation scheme, which provides irrigation for horticulture in the Kundasang areas.

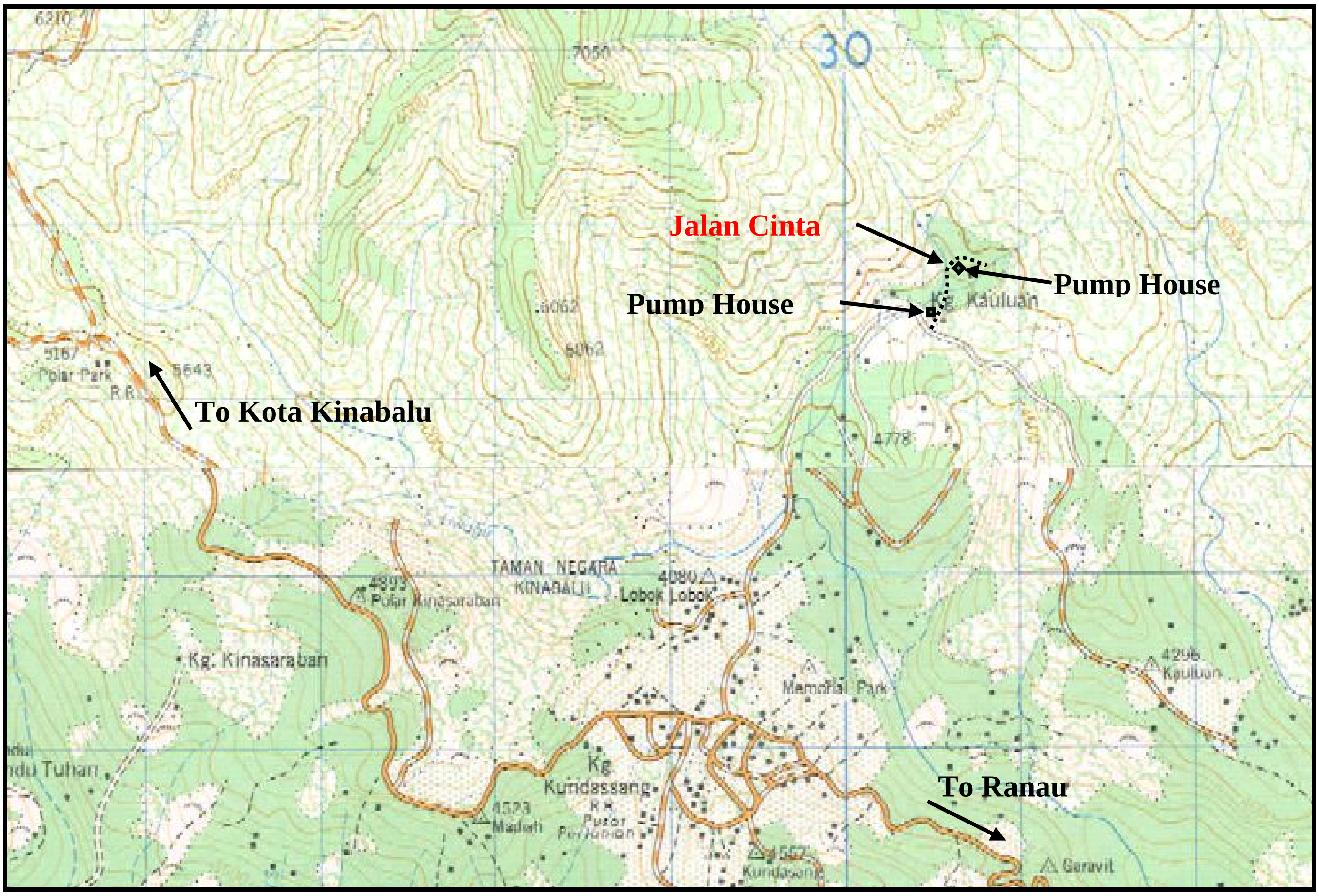


Figure 1: Plan View of the Site

Photo 1: Overall Site Terrain

It was also intended to be the power scheme for Sabah Electricity Board (SEB). The Mesilau Mini Hydro project was commissioned in 1983 but has not been used since 1985. In October 1987, a massive slip occurred and tilted the pump house, PH-2 and part of the pipeline. From the site observation, the pump house has suffered distresses due to differential settlement and lateral ground movements. Photos 4 and 5 show the shear cracks and the detached floor slab respectively as a result of the ground movements.

As a result of ground movement, the concrete drains on the higher ground along the roadside also show serious cracks due to shearing and tensioning. No indication of damage on drains due to compressive thrust at the lower passive zone was observed except some distortions of the T-junction concrete drain sump as shown in Photo 6. This is because the concrete drains were constructed across the active wedge areas where tension cracks occur and probably did not extend to the passive wedge at the lower portion of the landslide masses. Repair works have been carried out to seal the cracked drain. Photo 7 shows the repaired drain.

The road pavement along the affected chainage generally shows tension cracks, potholes, Settlement and bearing capacity failure, probably due to weak subgrade as a result of ground movement. This is shown in Photo 8. The rapid rate of distresses on the pavement indicates that the ground movements are still very active.

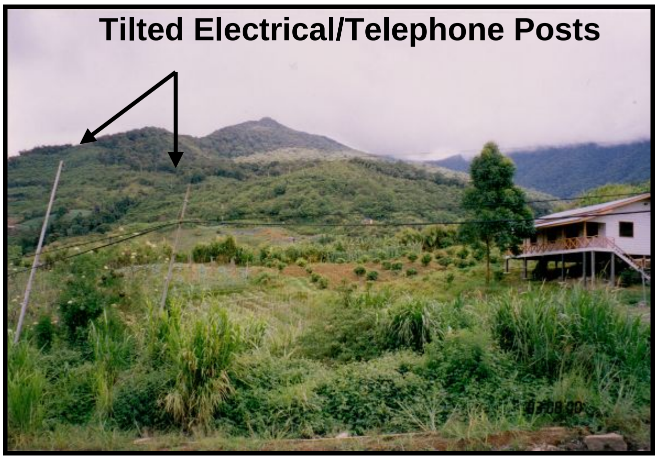


Photo 2: Tilted Electrical/Telephone Posts

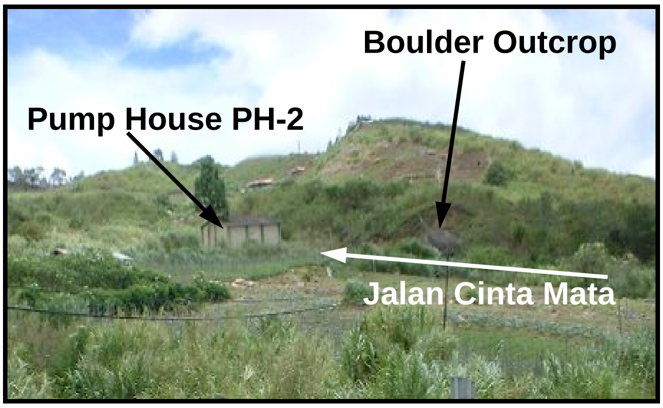


Photo 3: Overview of Jalan Cinta Mata Entrance

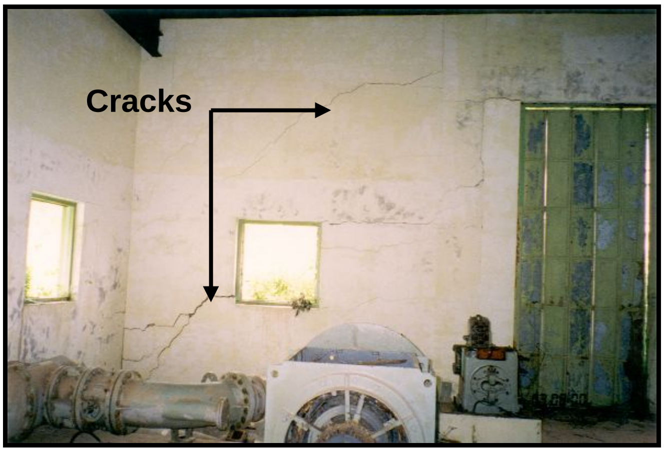


Photo 4: Distressed Pump House

There is an abandoned resort with some signs of distresses on the right hand side of the road. It seems that there is some ground movements at the founding ground of the resort, but it is uncertain whether it is associated to the one that is currently understudied.

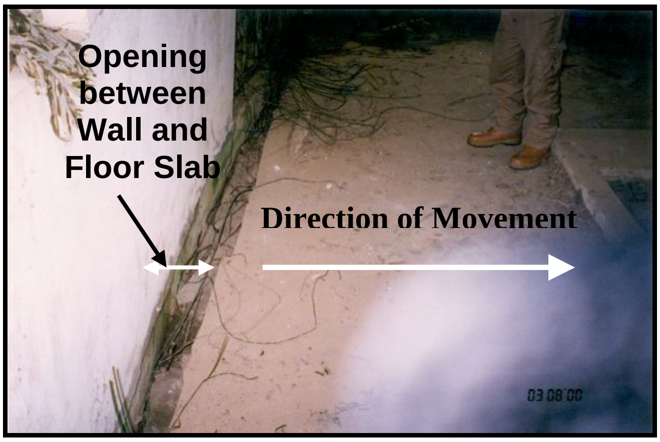


Photo 5: Distressed Pump House

Photo 6: Distorted Drain Sump

3.0 TOPOGRAPHY & GEOLOGICAL CONDITIO`NS

The site is located at the fan shaped deposits of Pinosuk Gravels from Mt. Kinabalu as shown in Figure 2. The few rivers, namely Sg. Kuamanan, Sg. Mesilau, Sg. Tarawas and Sg. Mantaki, and their tributaries bisect the Pinosuk Plateau and form many gullies. The catchments of these rivers are shown in Figure 3. Reduced levels of the study area range from RL1335m to RL1500m. The general gradient of the natural ground around the studied area is about 10°.

Photo 7: Repaired Cracked Drain

Photo 8: Depression on Road Pavement

The studied area is surrounded with number of rivers, namely Sg. Mesilau on the east and Sg. Kuamanan on the west. Most rivers near the studied area derive from the Mt. Kinabalu and run towards south and south-eastern directions. These rivers bisect the post-glacial deposits by erosion process and form the potentially unstable bisected fragments of soil masses.

Kundasang-Ranau area is the only area in Malaysia, which possesses temperate climatic in this tropical country and unique landscape formed by glaciation and ancient mudflow. These geological transportation processes has brought the deposits even to Ranau, a small town 13km from Kinabalu National Park.

The Pinosuk Gravels were deposited during the late Pleistocene, approximately 37,000 year BP or older. It generally consists of two units: Lower and Upper Units representing two phases of deposition. The Lower Unit consisting of shaped edged sandstone and ultrabasic rock was deposited by glaciation whereas the Upper Unit made of rounded granodiotite was by ancient mudflow due to thawing of the glacial and ice cap at Mt. Kinabalu. From the petrography study, the original sources of Pinosuk Gravels are the Tertiary sediments, namely Trusmadi Formation (Lower Paleocene-Upper Eocene) and the Crocker Formation (Lower Paleocene-Upper Oligocene), in which the materials of these two formations were transported by the aforementioned geological processes and finally deposited at the current location. The Trusmadi Formation comprises predominantly grey to dark grey shale/mudstone, with subordinate siltstone, sandstone and volcanics, whereas the Crocker Formation comprises predominantly sandstone with subordinate siltstone, red and grey shale/mudstone. Both tertiary rock formations are highly folded, faulted and fractured. The granodiorite materials found at the Pinosuk Gravels area were actually the emplacement of Mt. Kinabalu, while the ultrabasic boulders came from the ultrabasic rock that separates the granitoid rock from the Tertiary sediments. Sarman, M. & Komoo, I. (2000) have given a very elaborated description of the Pinosuk Gravels. Figure 4 shows the geological formation of the site. A major north-south fault (the Mensaban Fault I) separates the Trusmadi and the Crocker Formations just east of the Kundasang-Golf Course road. The 1.2km road traverses a sheared or brecciation zone within the Trusmadi Formation. At the starting point of the Jalan Cinta Mata, some recent excavations reveal dark grey shale belonging to the Trusmadi Formation.

A geological walk-around at the studied area has confirmed the geological formation and aforementioned geological conditions. Photos 9 and 10 show the Pinosuk Gravels outcrops at the Sg. West Mesilau and the adjacent cut slope along the road respectively. Photo 11 shows the granitic boulders on the Desa Cattle Farm.

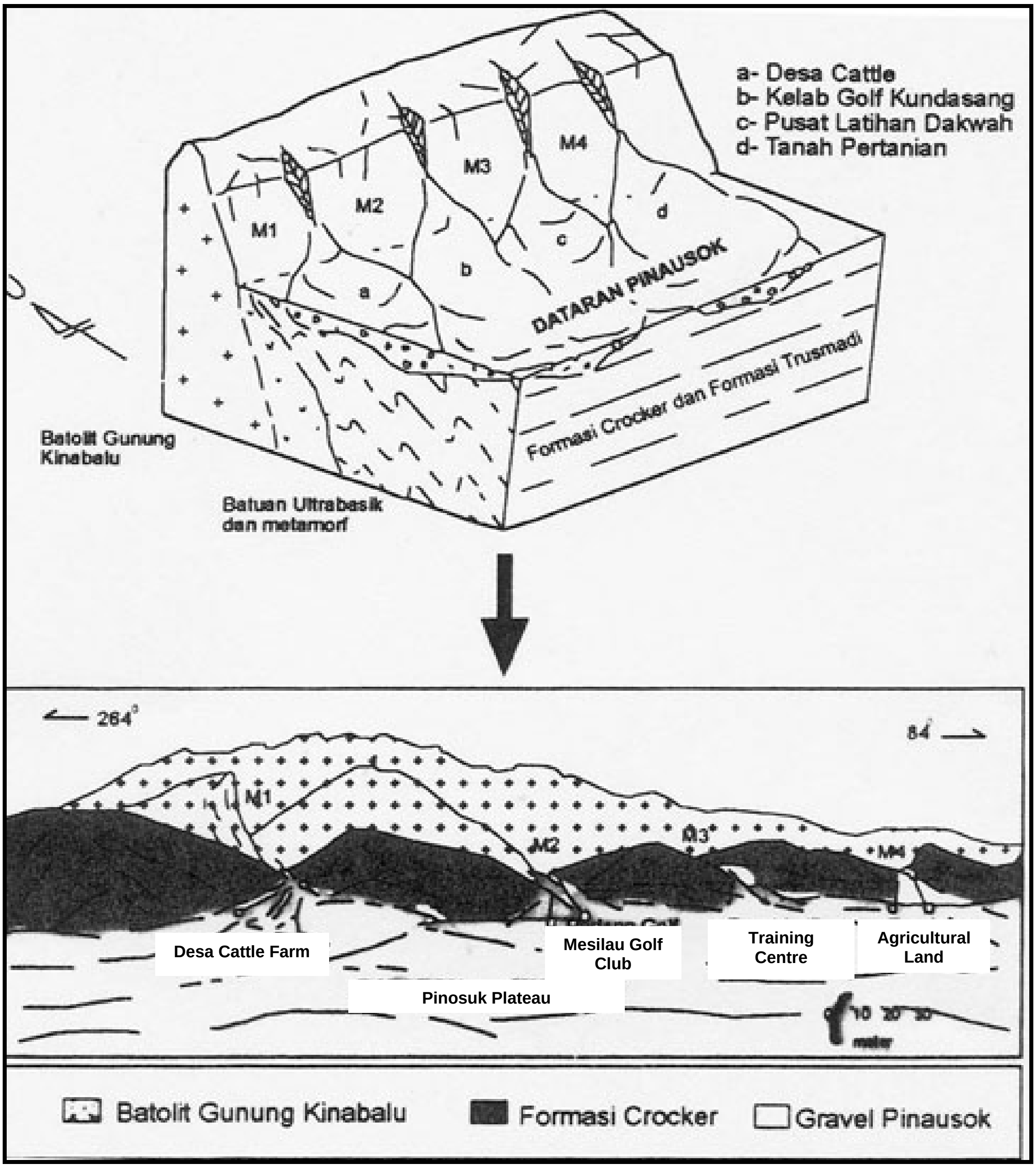


Figure 2: Deposition of Pinosuk Gravels

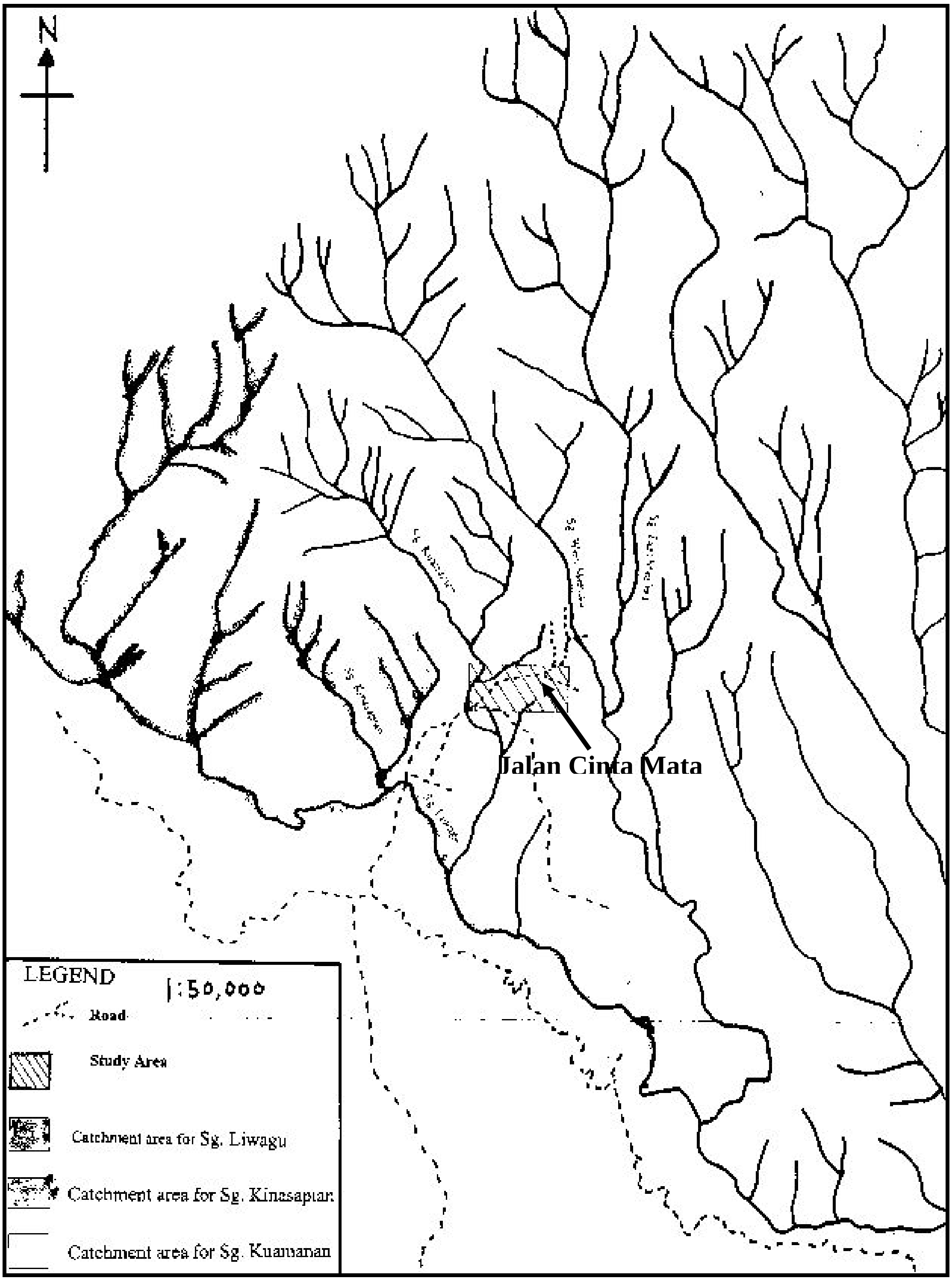
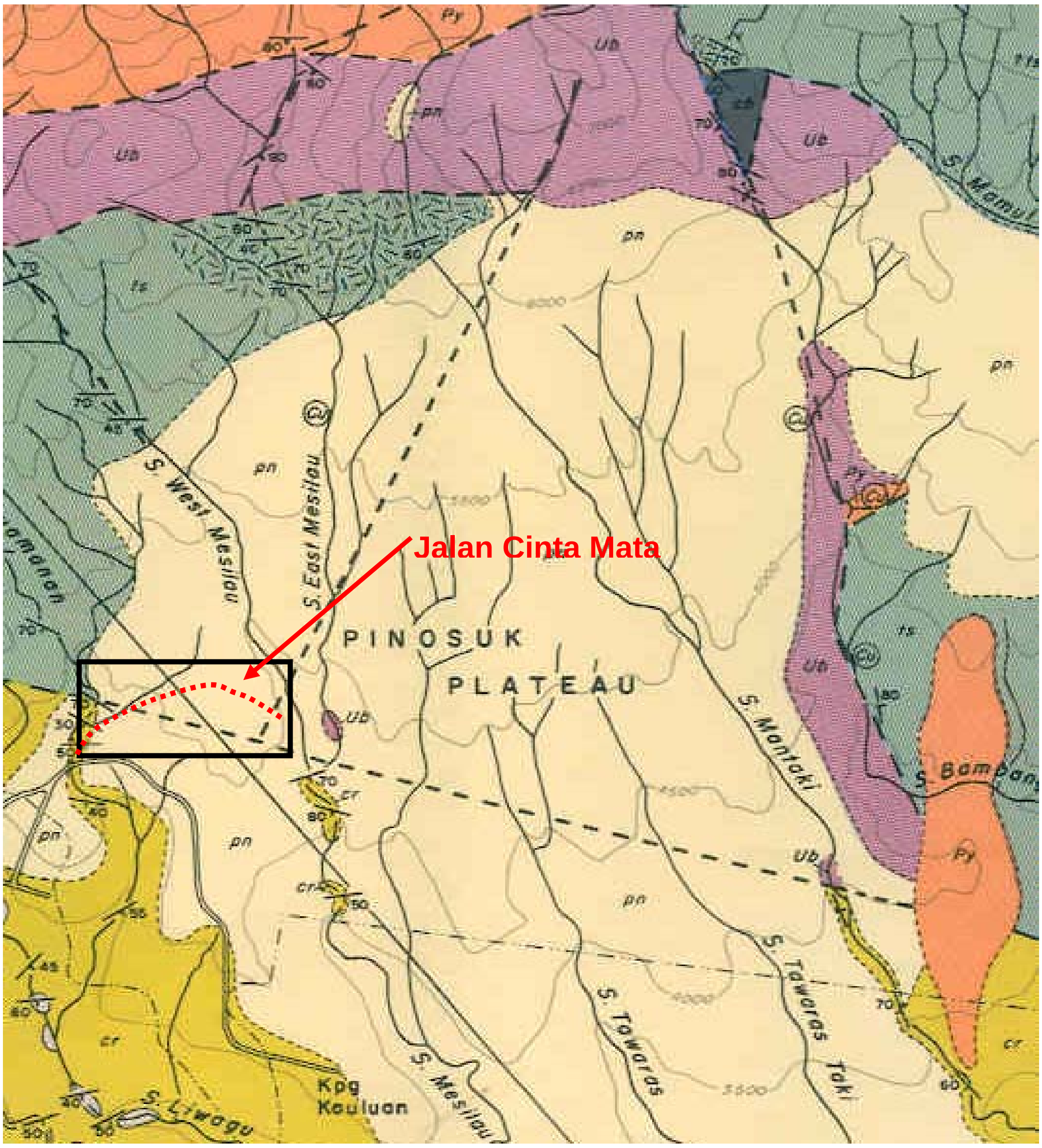


Figure 3: River Catchment of Kundasang Area



Sedimentary Rocks

pn	PINOSUK GRAVELS (Upper Pleistocene): Poorly consolidated unsorted gravel up to boulder size in a sandy to clayey matrix
cr	CROCKER FORMATION (? Ta - Te4): Strongly folded and faulted sandstone, siltstone, red and grey shale, mudstone and argillite
ts	TRUSMADI FORMATION (Tab): Strongly folded and faulted grey and dark grey argillite, slate, siltstone and sandstone with volcanics (v)

Intrusive Rocks

Py	Adamellite porphyry and porphyritic adamellite
Ub	Serpentinite and serpentinized peridotite, contact metamorphosed in part

Figure 4: Geological Map

Photo 9: Outcrop at Sg. Mesilau

Photo 11: Granitic Boulders at Lower Plateau

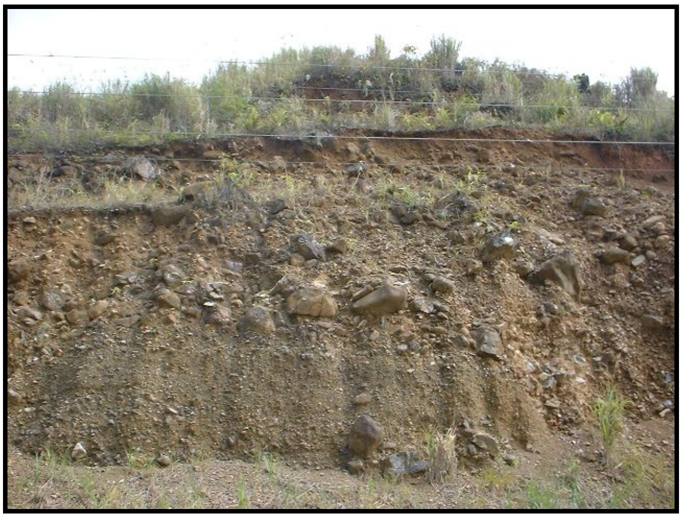


Photo 10: Outcrop at Cut Slope

Photo 12: Granitic Boulder at Lower Plateau

4.0 AERIAL PHOTOGRAPHS

From the 1970 aerial photographs available at Department of Survey and Mapping Malaysia (JUPEN), the road to the golf course has not been built and the vegetation at the current road alignment (from pump house PH-2 at the junction to pump house PH-1 on the hill top near entrance to Desa Cattle Farm) is somehow very scarce. The 1984 photos show a very clear picture of this road with the two structures appeared to be the pump houses. Kundasang areas have been extensively developed as shown in the 1984 and 1986 photos and the road alignment turning into the Jalan Cinta Mata has shown some realignment, which can be due to either creep movement or by road realignment works. A documented massive slip on the current road alignment has been reported in October 1987.

5.0 SITE INVESTIGATION & MONITORING

There was a subsurface investigation (SI) programme consisting of 6 exploratory boreholes with inclinometers installed in every borehole. An additional borehole was sunk to reinstall the inclinometer (IN-1A) for replacing the inclinometer IN1, which has been sheared off during the monitoring period. Beside the boreholes, standpipe piezometers were installed to the depth of 10m for groundwater monitoring. The SI and instrumentation layouts are shown in Figure 5.

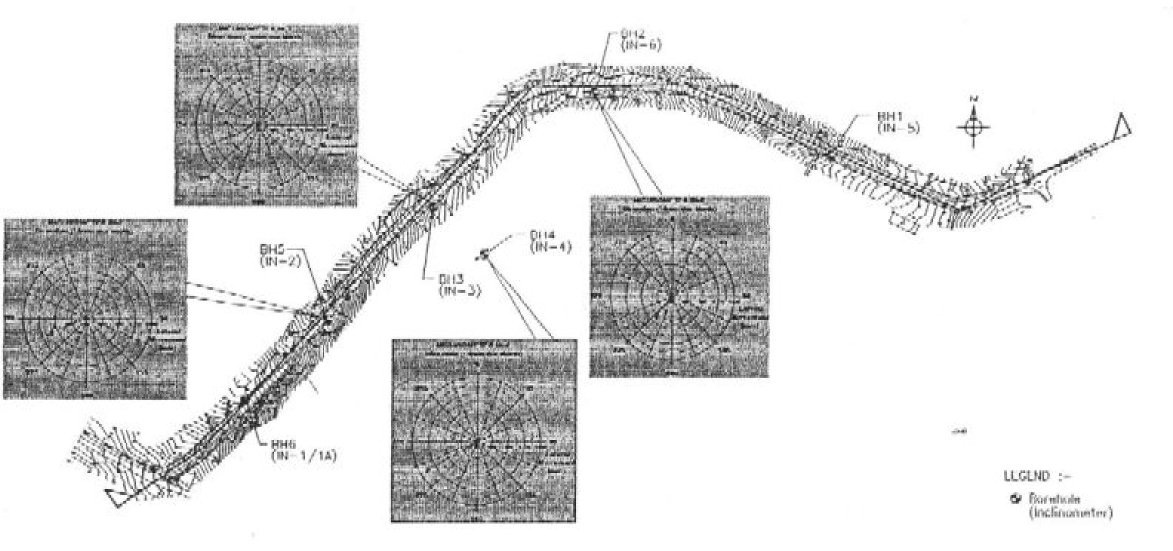


Figure 5: Layout of SI Boreholes and Instrumentation

The interpreted borelog profile and the groundwater conditions are shown in Figure 6. From the inclinometer results, it is observed that distinct shear planes can be identified, particularly at inclinometers, IN-2, IN-3, IN-4 and IN-6. The direction of lateral movement of these inclinometers is in the narrow range between 225° and 250°. The maximum lateral movement is 140mm, which is in Inclinometer IN-4. The rates of maximum lateral ground movements in these inclinometers are generally in the range of 2mm/week to 14mm/week with few exceptional cases of maximum up to 21mm/week as shown in Figure 7. Whereas, inclinometers IN-1, IN-1A and IN-5 show lateral movement profile of a buckling casing and indicate that there is some compression within the subsoil at these inclinometers.

Groundwater measurements recorded in the piezometers also indicate high water table in the subsoil, which is about 1.5m to 2.5m below the ground level.

From the interpreted consolidated isotropically undrained (C.I.U) triaxial test results, the effective shear strength of the subsoils with vertical effective stress level ranging from 50kPa to 450kPa indicates : $\phi' = 21°$ and $c' = 10kPa$, as shown Figure 7. The soil samples recovered from the boreholes are generally Silty Clay with sedimentary clast and occasionally Sandy Silt at the upper layer.

Six undisturbed soil samples near to the identified slip plane have been selected, reconstituted and tested in direct shear box to indicate the shear strength of the fine content of the soil mixtures. The test specimens were prepared from the soil particles passing through the 425μm sieve with the adjusted moisture content. The normal effective stresses on these specimens were applied based on the corresponding vertical in-situ effective stresses. The interpreted soil strength from direct shear box tests is fairly near to the CIU strength with two data points having slightly higher values. This is also shown in Figure 8.

Other interesting findings from the laboratory tests are as follows:

1. The natural water content in the subsoil of the moving soil mass is lower than the plastic limit of the subsoil. The natural water content of the soil samples is in the range from 7% to 13%.
2. The bulk density of the subsoil is generally in the range between 21 to $23kN/m^3$, except for sample, MS-6 in borehole, BH-5, which has the bulk density of $23.69kN/m^3$.
3. The undrained shear strengths of most undisturbed samples are considerably low as shown in Figure 9, which are

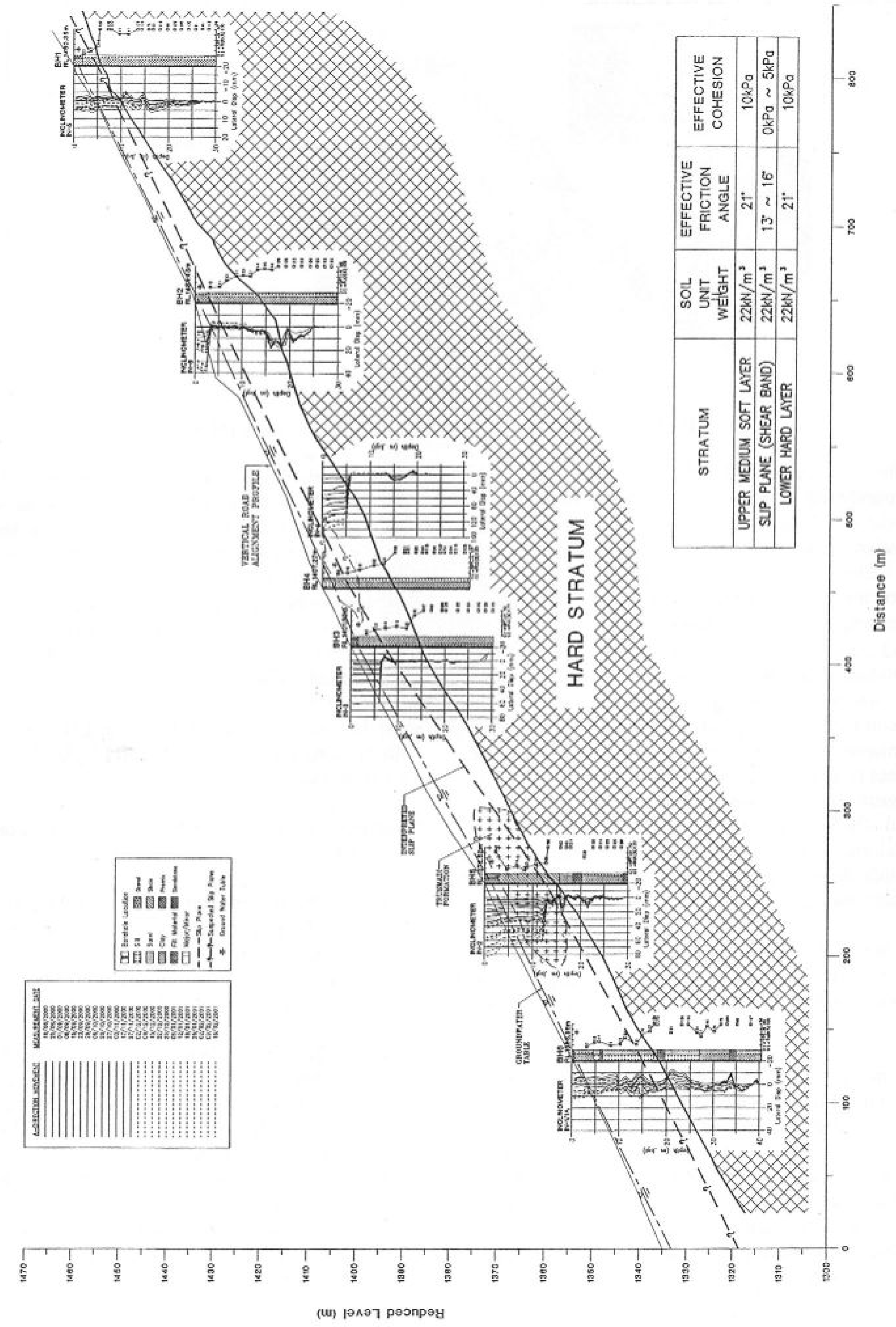


Figure 6: Subsurface Profile and Inclinometers Results

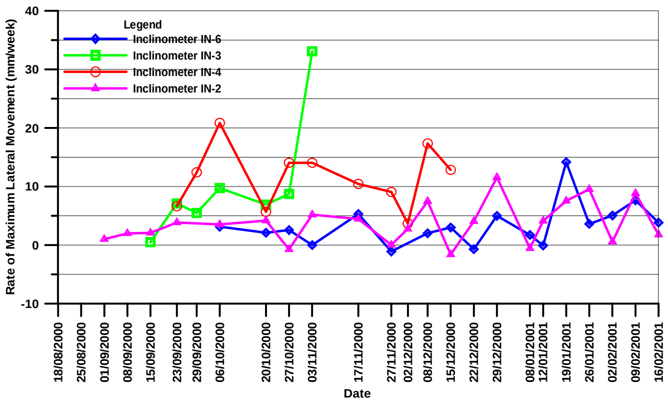


Figure 7: Rate of Maximum Lateral Movement

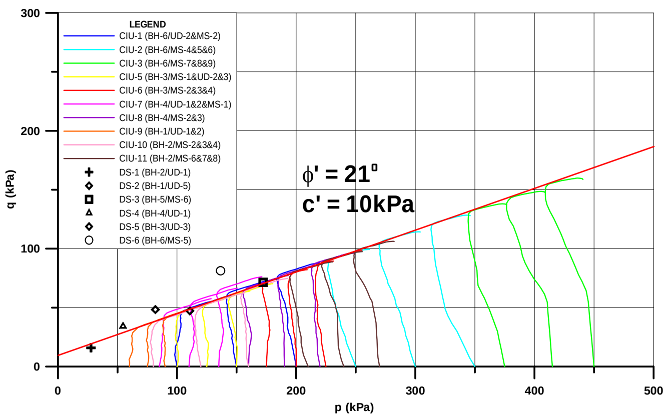


Figure 8: C.I.U. Tests & Direct Shear Box Tests

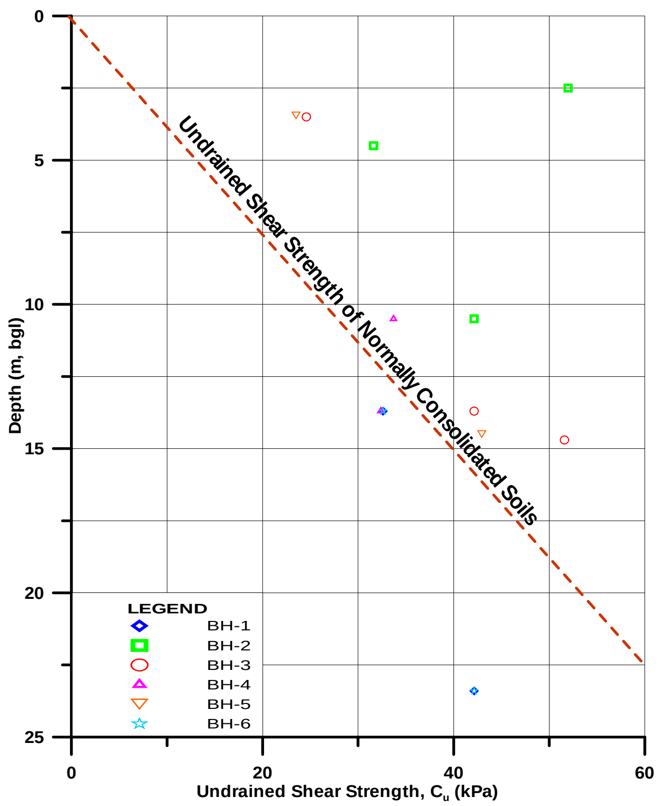


Figure 9: Undrained Shear Strength Tests

6.0 VISUAL INSPECTION OF STRUCTURES AND THE SURROUNDING

During the site visits in the months of August and September 2000, the followings were observed.

1. The electrical posts and telephone posts show tensioning in the wires or cables within the affected area. Some of the posts were tilted and indicating direction of ground movements. The mapping of relative ground movements based on the conditions of the tilted electrical and telephone posts is shown in Figure 10.
2. The pump house, PH-2, at the left-hand-side of Jalan Cinta Mata near to the road junction shows a substantial displacement as the structure has tilted and displaced significantly from its original location.
3. The repaired and new tension cracks along the roadside drains were observed.
4. The road pavement at the affected areas was all damaged primarily due to differential displacement on the road subgrade. It was also observed that the development of new tension cracks within the affected area was fairly active. Within few months of monitoring period, the changes of the site condition were obvious.
5. Numbers of large granitic boulders were observed at the surrounding of the area. Photo 12 shows the gigantic granite boulder on the opposite side of the borehole, BH-6. This provides good evidence on the historical transportation of the glacial till derived from the Mt. Kinabalu. The walk-around by our geological expert on 22 September 2001 looking for the geological features on the outcrop and the exposure at the river has confirmed that the site is within the Pinosuk Gravels. An outcrop consisting of red shale, which is believed to be the remnants of the lower Trusmadi Formation, was observed in borehole BH-5 and the adjacent boulder outcrop.

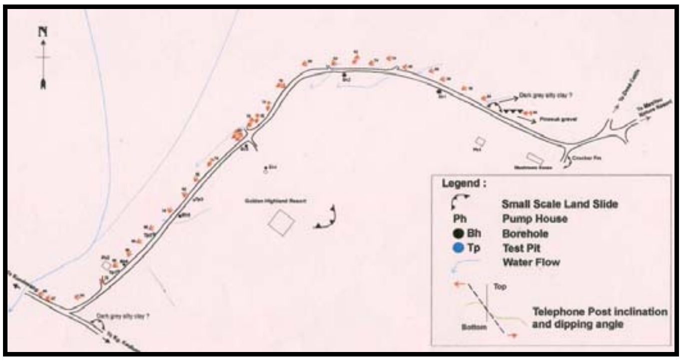


Figure 10: Site Mapping on Ground Objects

7.0 ENGINEERING ASSESSEMENTS

The interpreted soil strength (c'= 10kPa, ϕ' = 20.5°) from the laboratory testing is generally much higher than the gradient of the road alignment and also the surrounding terrain. Theoretically, the underlying subsoil shall have sufficient strength to withstand the gravity action of the sloping soil masses against slope instability. This implies that there could be some important geological features causing the instability not captured in the present investigation.

Three cases have been established for the slope stability back-analyses with the monitored groundwater profile to reveal the possible combination of the shear strength parameters (c' and ϕ') of the instability with safety factor of 1.0, to 1.4. These cases of back-analyses are assessed in the conditions as follows:

Case A : Failure case as per the detected slip plane.
Case B : Same as Case A except with inclusion of river channel.
Case C : Localised slope failure surface at the river channel.

Case C analyses are carried out solely to check the upper bound of the soil strength as such case will certainly require higher strength to keep the slope in stable condition as compared to the other two cases. But the back-analysed soil strengths are still lower than the aforementioned interpreted soil strength from the laboratory tests if cohesion intercept is taken as 10kPa. If the cohesion is ignored, the back-analysed friction angle is same as the friction angle interpreted from the laboratory test results, which means the safety factor for the localised stability at the river bank is just about 1.0. If such localised instability can retrogress uphill to trigger the blanket sliding failure mode as indicated from the inclinometers, there shall be some multiple shear planes in the inclinometer results. However, there is no obvious multiple shear planes observed in all six inclinometers. Therefore, such mode of failure is ruled out for further investigation.

The results of these analyses are shown in Figures 11, 12 and 13. The possible range of the back-analysed shear strength parameters at the shear plane are : c'= 0 to 5kPa, ϕ' = 13° to 16°. These back-analysed soil strengths should be verified by appropriate testing on the soil samples within the slip surface during the detailed SI

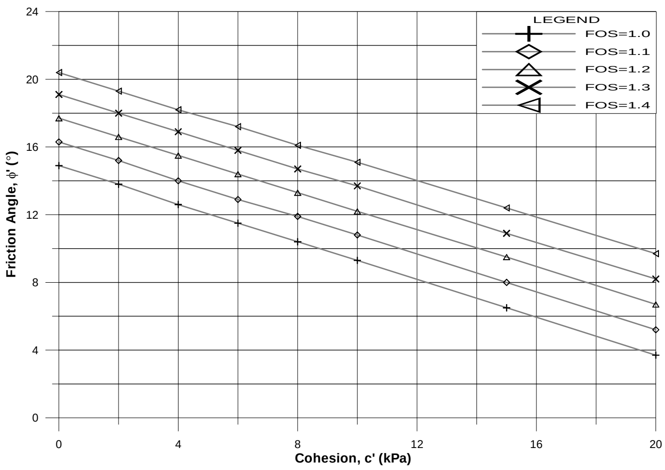


Figure 11: Back-Analysed Strength Parameters for Case A

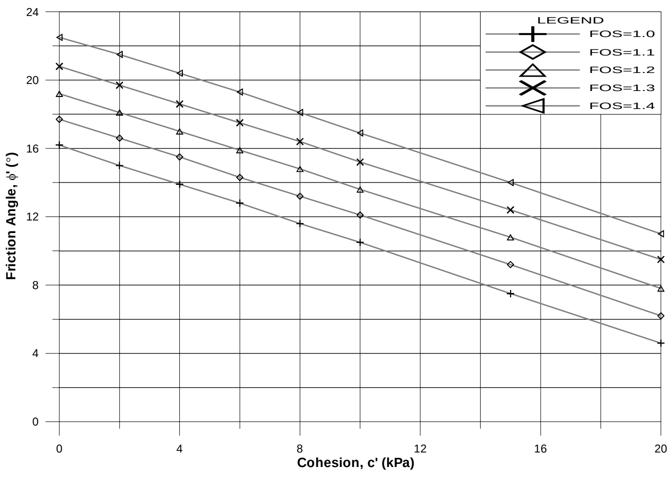


Figure 12: Back-Analysed Strength Parameters for Case B

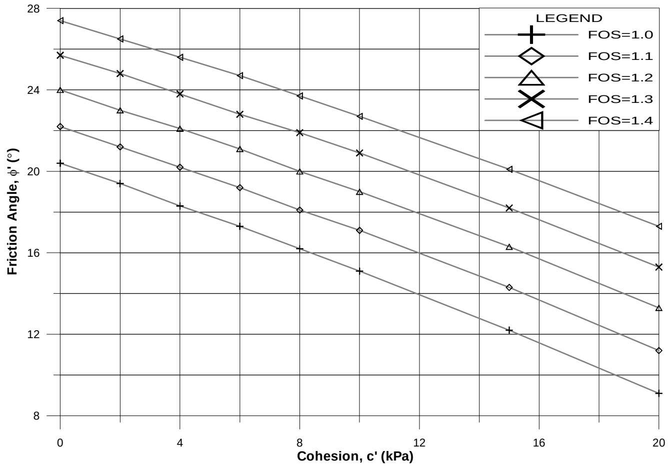


Figure 13: Back-Analysed Strength Parameters for Case C

7.0 FINDINGS & RECOMMENDATIONS

The investigation of the distressed access road has the following findings and recommendations:

Findings: The existing road alignment is confirmed located on the Pinosuk Gravels of glacial deposit. An obvious slip plane has been detected from the inclinometer results and the fairly high piezometric level of groundwater has been established in the standpipes. The depth of slip plane varies from about 6m at the higher ground to about 15m at the lower ground near the starting chainage of Jalan Cinta Mata. The direction of ground movement is generally towards south-west (approximately 225° to 250° clockwise direction from the north).

The interpreted strengths of the subsoil have sufficient safety factor, i.e. at least more than 1.5 from the back-analyses for Case A, against slope instability as the topography of the road alignment indicates the general gradient of about 10°, which is much gentler than the internal friction angle of the subsoil at the site. Therefore, it is believed that there should be some small but important geological features not detected in the investigation works. The back-calculated strength parameters are: Cohesion, C'= 0 to 5kPa and Effective Friction Angle, ϕ' = 13° to 16° respectively. These ranges of strength parameters are believed to be the residual strength of the landslide masses as the magnitude of slip movement is significant. These back-calculated strength parameters can be used for remedial design.

Recommendations: Further investigation works are needed for the detailed design of the remedial works.

A detailed second stage investigation programme and topography survey of wider coverage shall be carried out for the detailed remedial design of the unstable soil masses at the original alignment upon deciding to remedy the existing road alignment. It shall include: A) Trial pits excavated down to the detected shallow shear plane shall be carried out to obtain high quality block sample containing the shear plane for direct shear box tests. B) For deep seated slip plane, continuous undisturbed sampling using borehole can be considered. Multiple reversal shear box test can be carried out to obtain the residual strength at the slip plane of the landslide masses and compare the residual strength with the back-calculated strength parameter to improve confident level. C) Those recommended earlier, such as Total Station Survey on wider coverage of the studied area and the downhill river areas.

8.0 REFERENCE

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