



The use of seismic refraction method in slope failure investigation

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Abstract: This study is focused on a slope failure investigation for a site of Semantan Formation located at the Temerloh-Mentakab route, Pahang. Ground investigation employing seismic refraction survey was conducted followed by trial pits, Macintosh probe and wash drilling with standard penetration tests (SPT). Laboratory tests that includes classifications, drained shear box and consolidated undrained triaxial with pore pressure measurements were also carried out. The results of the velocity profile from several spread lines have indicated a possible shallow failure from a weak soil material that overlies a deeper sliding failure mass. The two possible sliding surfaces interpreted from the seismic velocity profiles were found to correlate well with the Macintosh probe and the SPT conducted on adjacent boreholes. A lateral variation in the velocity profiles from several spread lines have shown that the dominantly argillaceous material could be delineated from the dominantly arenaceous material that has been unaffected in the slide and conforms well with the geological facies of the site. The topography of the post failure ground level and the probable slip surface, interpreted from the seismic refraction profiles were then represented using a 3-D graphic software in order to evaluate the overall sliding mass.

INTRODUCTION

A slope failure was first reported at the Microwave Station of the Temerloh-Mentakab road sometime in 1985. The location map of the slope failure and its adjacent area is shown in Figure 1. In early 1995 the slope failure was again reported to have reactivated with water seeping continuously from the toe of the slope to the side table and onto the road surface after a heavy rainfall. Cracks were also observed to appear on the bituminous road surface. The Public Works Department Research Institute was called in to investigate the cause of the failure and recommend the slope remedial measures. A site investigation program was initiated in the middle of 1995 with four numbers of motorised hand boring. However the drilling with standard penetration tests had failed to indicate any conclusive slip failure plane in order to help the geotechnical engineer determine the depth to terminate the earth retaining structures for slope remedial design. Following this, a geophysical method was undertaken with the aim that it will provide some indication on the sliding plane of which results from previous motorised hand

boring had failed to provide. Further detailed ground investigations were then employed to compare and validate the results from the seismic refraction survey. Disturbed samples from wash drilling and undisturbed bulk samples obtained from trial pits were then tested in the laboratory to obtain their basic and shear strength properties.

THE SEISMIC REFRACTION METHOD

The basic principles of the seismic refraction method have been described in detail by Musgrave (1967), Dobrin and Savit (1988), McCann and Forster (1990) and Telford *et al.* (1990). The method is widely used in civil engineering applications to determine the depth and rippability of bedrock particularly in site investigations for roads and tunnels. There are numerous case histories on the use of this method in a wide variety of situations (Ripepe *et al.*, 1990; McCann and Forster, 1990).

Interpretation of the results from a seismic refraction survey is based on horizontal and dipping strata, each of which has a discrete compressional or shear wave velocity increasing with depth. In a

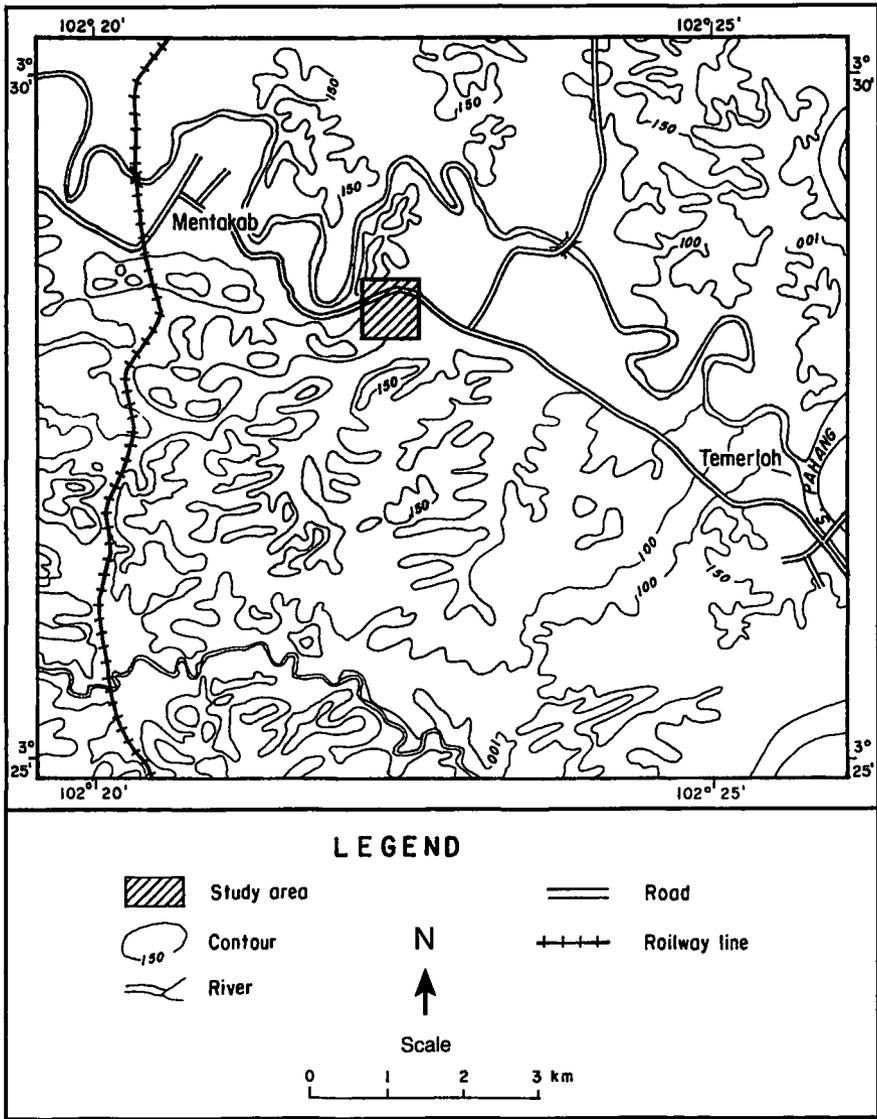


Figure 1. The location of the study area.

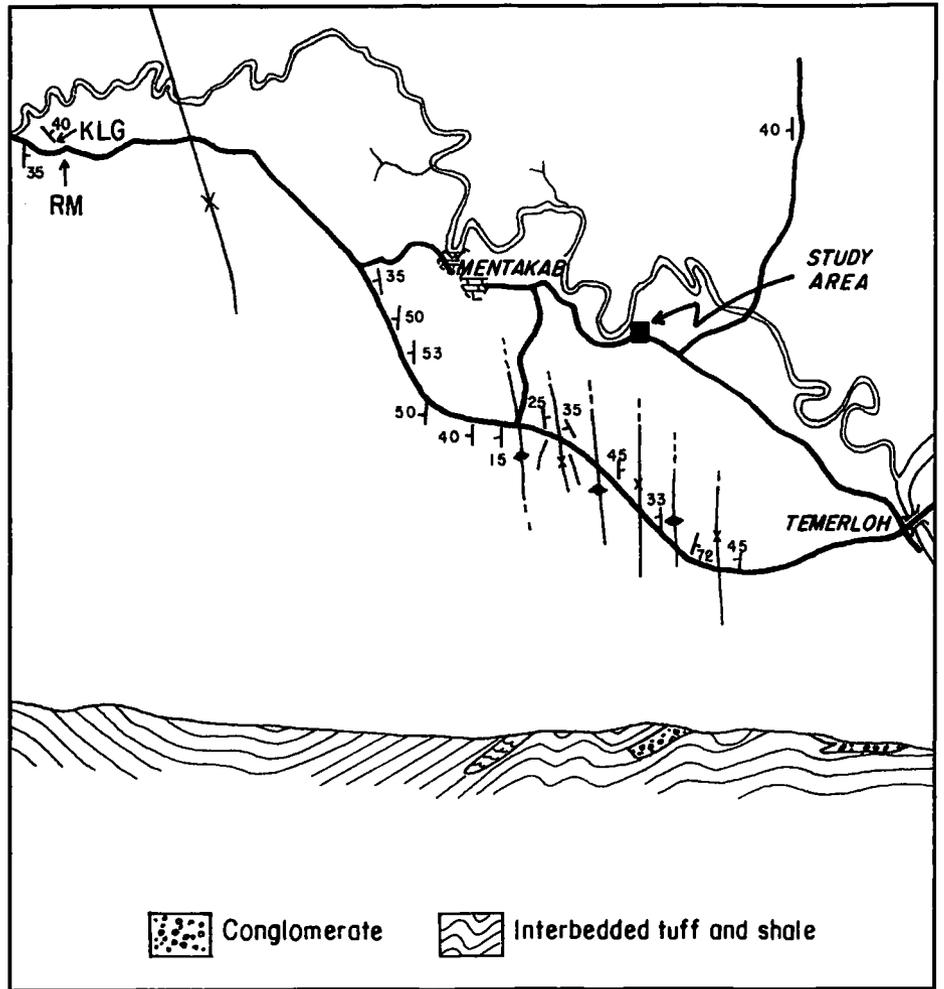


Figure 2. Structural trend and geological cross-section along Karak-Temerloh highway.

landslide or slope failure, the soil properties of the disturbed failure material are in general lower in terms of shear strength, rigidity, bulk density and porosity as compared to the original ground. As such, both the compressional and shear wave velocities are expected to be lower in the failure material. At the same time, attenuation of both compressional and shear wave increases significantly in the slope failure material and this may cause some limitations to the use of low energy seismic source such as the hammer.

GEOLOGY

The geology of the Temerloh-Mentakab bypass, along a road running more or less parallel to the road of the site where this slope failure had occurred has been described by Jaafar Ahmad (1976) and Kamal Roslan Mohamad (1989), has similar geological setting. The area is made up of argillaceous rocks of the Semantan Formation that comprises the tuffaceous sandstone interbedded with siltstone, mudstone and black shale. Two major directions of faults were reported by previous workers. The first fault runs parallel to the regional strike and the other at right angles to it. They are interpreted as a result of compressive forces acting

in the northeast-southwest direction during regional metamorphism. Tension joints were found and are commonly perpendicular to the bedding or foliation. In general the rocks of Semantan Formation have been folded into a series of anticlines and synclines as well as being faulted (Fig. 2).

Most of the rocks in the study area (Fig. 3) are highly weathered especially those of dominantly argillaceous facies. However the tuffaceous sandstone layer in a dominantly arenaceous facies is slightly resistant to weathering where their bedding traces can still be observed. The tuffaceous sandstone beds are light grey and range from fine to coarse arenaceous material. Graded bedding is common in these sandstones. The mudstone has been severely weathered, soft and it is usually dark to light gray. In areas where the rock is less weathered, it is generally of thin beds and sometimes shows fine lamination. The dominantly argillaceous facies occupies the eastern part whereas the dominantly arenaceous facies forms the western portion of the study area.

The rocks in the western portion of the study area are generally having north to north west strike with dip angles that range from 70–90 degrees. On the eastern side, the rocks are also having north to northwest strike but dips gently (~30°).

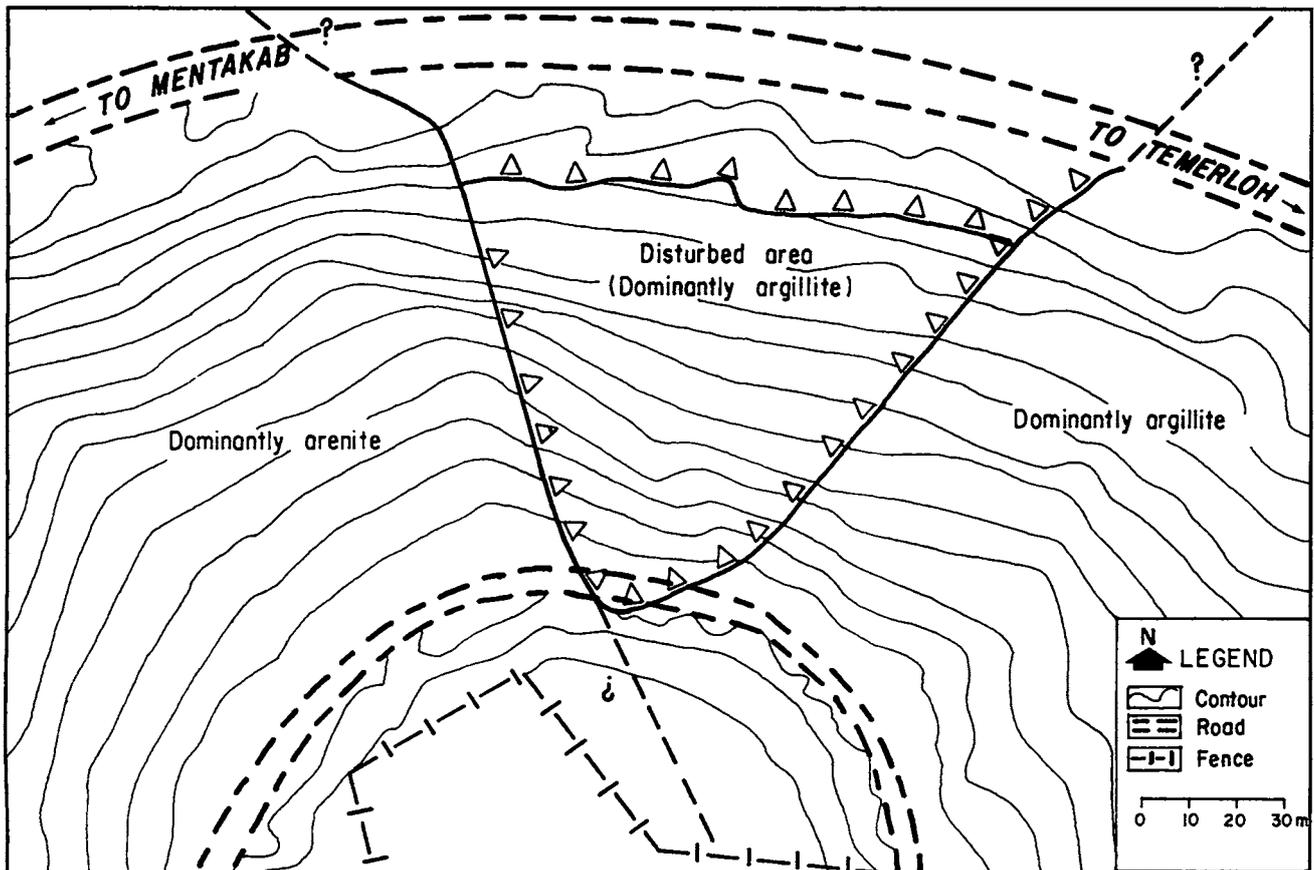
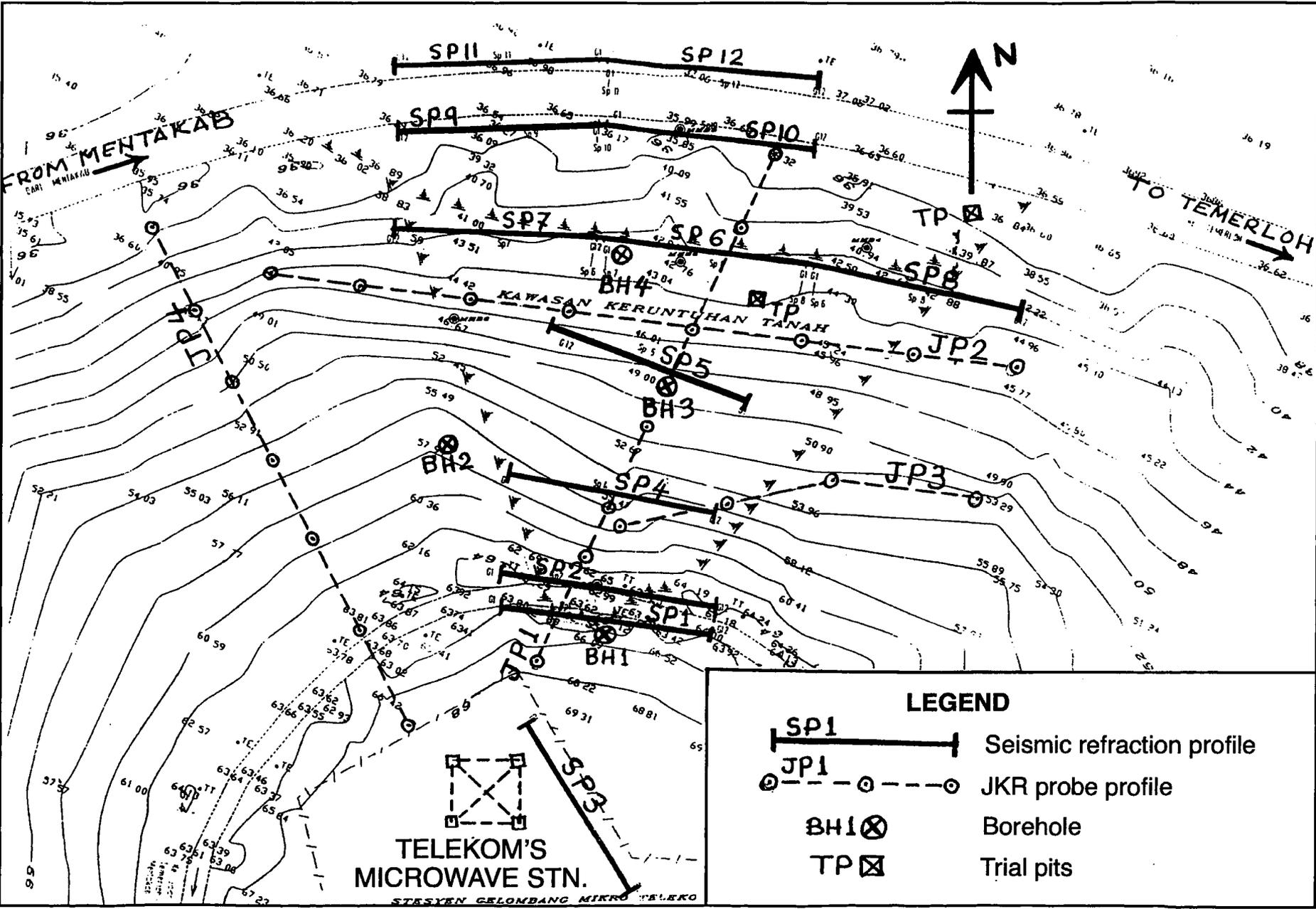


Figure 3. Geological setting of the study area.



LEGEND

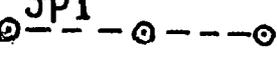
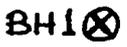
	SP1	Seismic refraction profile
	JP1	JKR probe profile
	BH1	Borehole
	TP	Trial pits

Figure 4. Locations of various ground investigations at the study area.

Table 1. Summary of the shear strength parameters from trial pits at the failure area.

Type of Test	Type of Soil	Cohesion (c') kN/m ²	Angle of internal friction (ϕ')
Triaxial-Consolidated undrained + pore pressure measurement — Test 1	clayey silt	30	22
Triaxial-Consolidated undrained + pore pressure measurement — Test 2	silty clay	10	24
Drained Shear box Test 1	—	2	33
Drained Shear box Test 2	—	7	22

GROUND INVESTIGATIONS

Seismic Refraction Survey

The seismic refraction survey was carried out with a Bison 5012 Instantaneous Floating Point seismograph which enable stacking of trace records with a 14 lb hammer. The geophones were of vertical 14 Hz type and are spaced at a constant 3 m interval throughout the survey. The seismic refraction survey was carried employing twelve spread lines denoted by SP1 to SP12 that are of 33 metres each. The spread lines of SP1, SP2, SP3, SP4 and SP5 were of single spread lines and SP6 to SP8, SP9 to SP10 and SP11 to SP12 a series of connected spread lines as shown in Figure 4. The spread line SP5 was carried out more or less parallel to the transverse Macintosh profile and adjacent to borehole location of BH3 whereas the continuous spread line that joints SP7, SP6 and SP8 is close to BH4.

The seismic trace records are stored in the equipment's volatile memory before they were transferred to computer disks in the 8 bit and 16 bit data format for latter processing. All the first arrivals of the p-wave were picked by a software Firstpix (Interprex Ltd.) which has enable the enhancement of amplitude, magnification and frequency filtering of the trace record to be carried out with the highest accuracy and resolution.

The final first arrival time picking from Firstpix was later saved in ASCII format to enable the file to be imported by the seismic refraction software Refract (Road Transport Authority, Australia) which is based on the General Reciprocal Method (Palmer, 1980).

Macintosh Probe

The Macintosh probe is a penetration test that

operates from a standard weight drop at a fixed height with the blow count recorded for every test depth until the termination depth of 400 blow count is reached. The tests were carried out to cover the longitudinal profile that runs from the top to the toe of the slope and the transverse profile that runs from the eastern to the western part of the slope as shown in Figure 4.

Drilling and SPT

A total of four wash drilling boreholes were carried out to obtain undisturbed samples with SPT at every metre interval. The test is based on a standard 63.5 kg weight drop at a fixed height and the blow count taken for a 300 mm penetration at each depth. The locations of the boreholes in relation to the other tests are shown in Figure 4. Boreholes BH3 and BH4 are the only boreholes that are located at the actual failure mass and are adjacent to spread line SP5 and SP6.

RESULTS AND DISCUSSIONS

Geotechnical

Laboratory tests

The top material from the laboratory classification tests has indicated that the soil materials are dominantly silty clay and clayey silt with traces of gravels up to about 18 to 25 metres below the ground level. Underlying these soil materials, silty clayey sand were dominant with the present of some silty clayey gravel. The liquid limit for the silty clay range from 28–52 percent and the plastic limit ranges from 18–27 percent.

The bulk sample taken from the test pit has been classified as silty clay and its shear strength properties is summarised in Table 1.

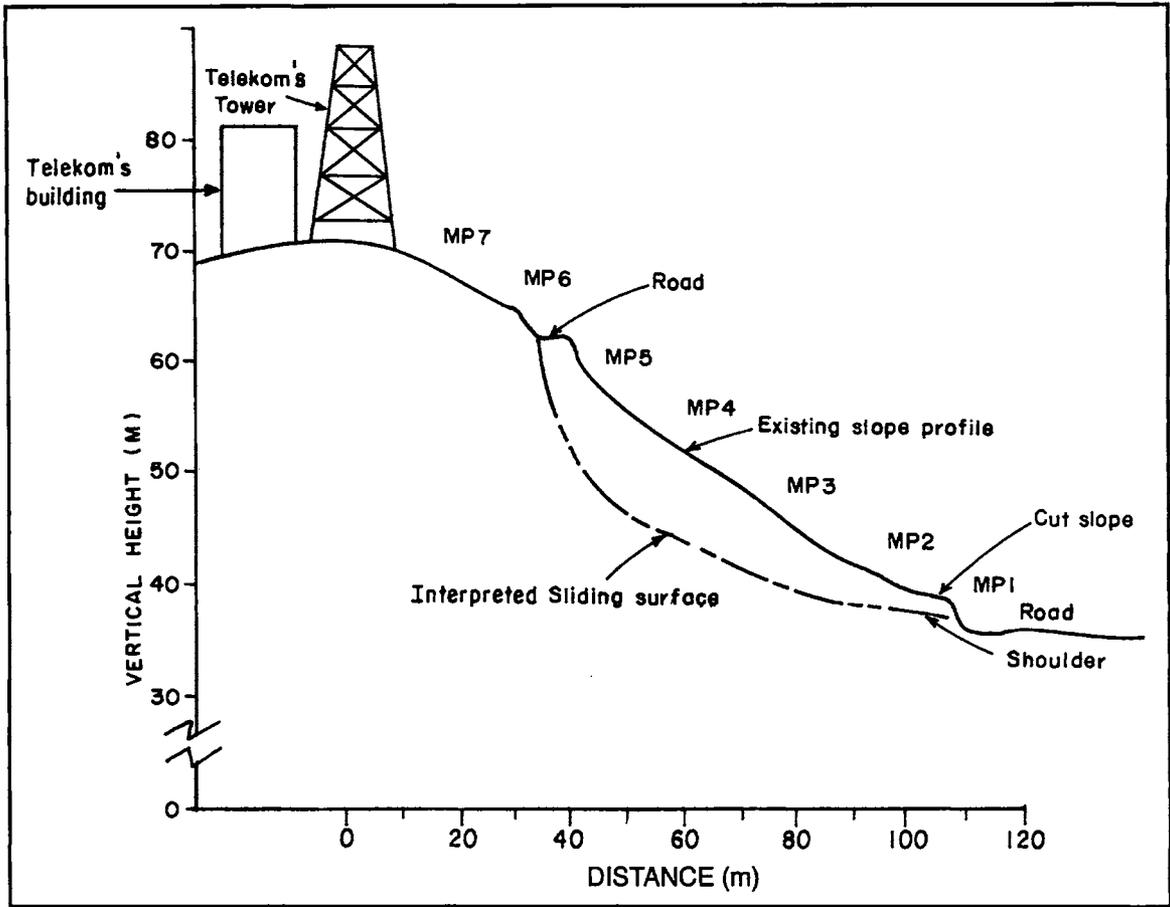


Figure 5. Longitudinal profile (JP1) of the interpreted slip plane from the Macintosh probe.

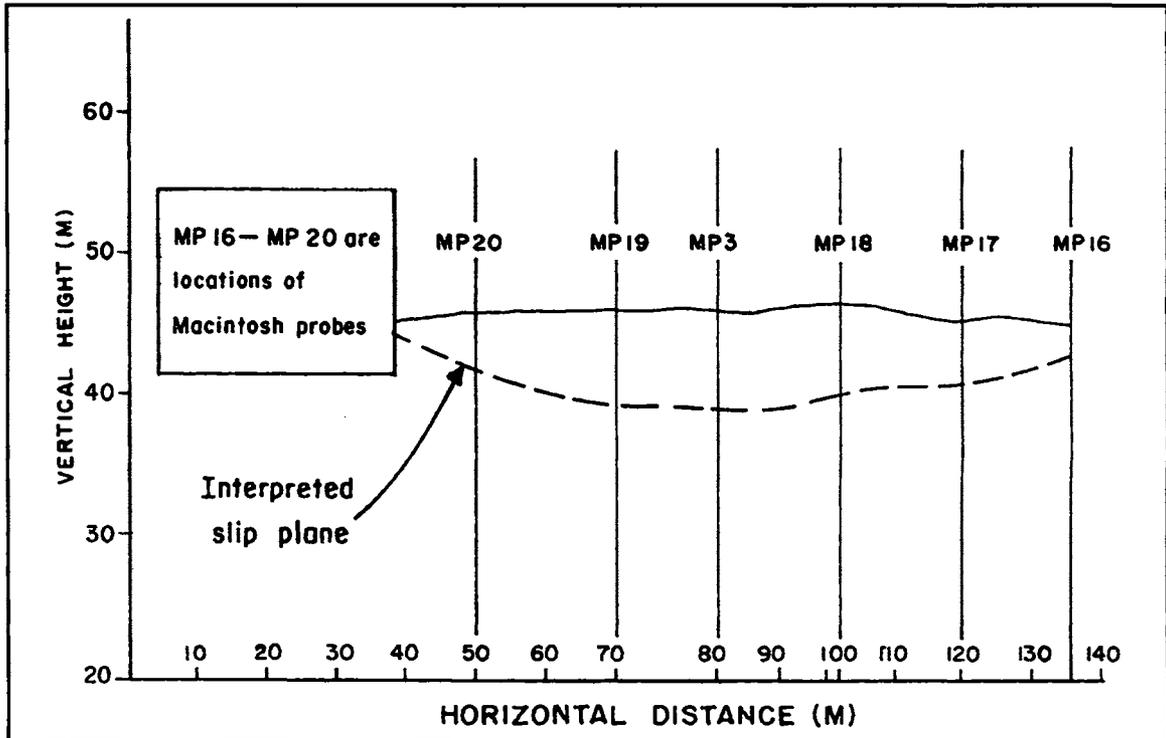


Figure 6. Transverse profile (JP2) of the interpreted slip plane from the Macintosh probe.

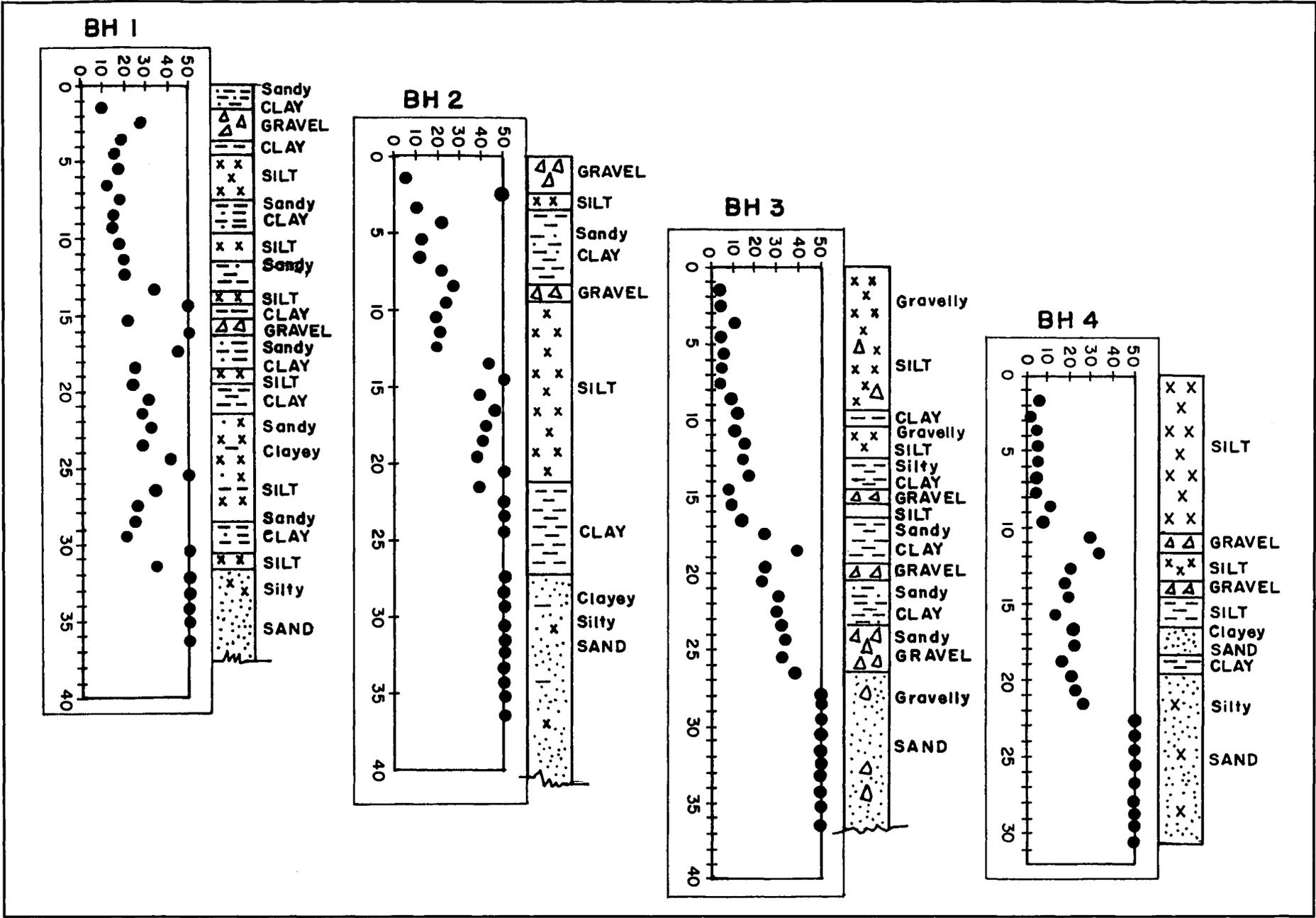


Figure 7. The soil profile with their SPT values.

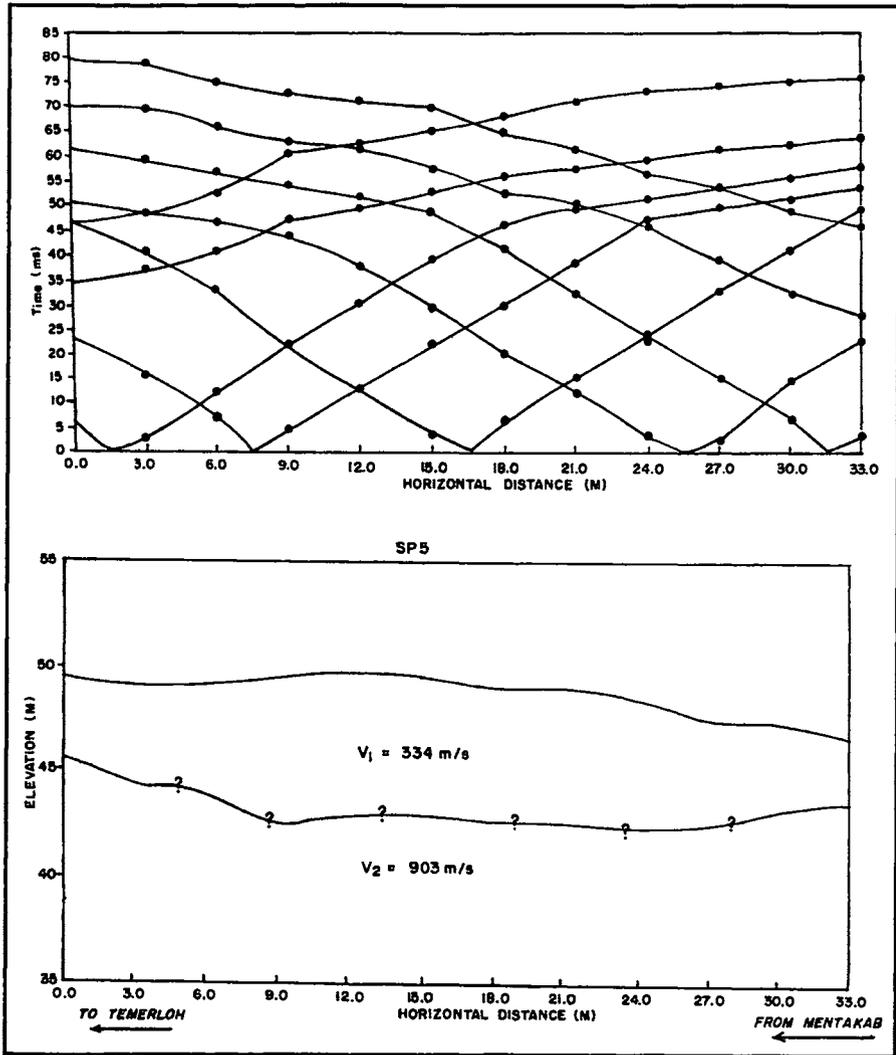


Figure 8. The distance-time plot and the subsurface profile for SP5.

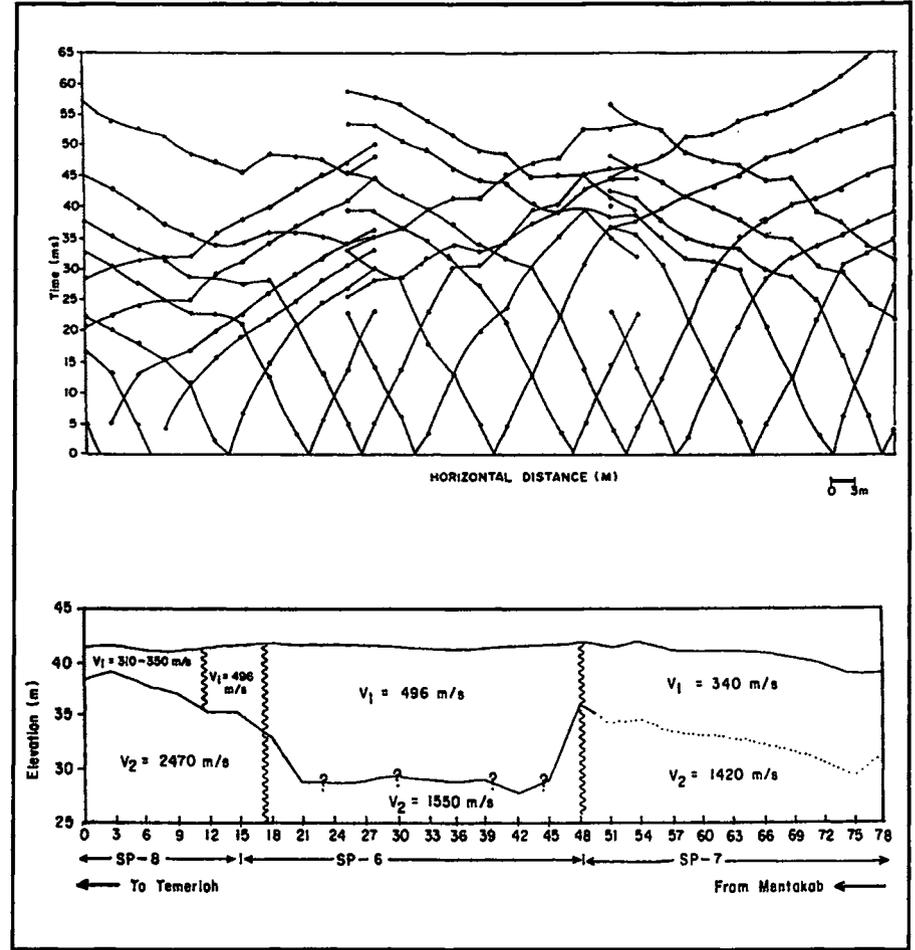


Figure 9. The distance-time plot and the subsurface profile for the continuous spread lines of SP6, SP7 and SP8.

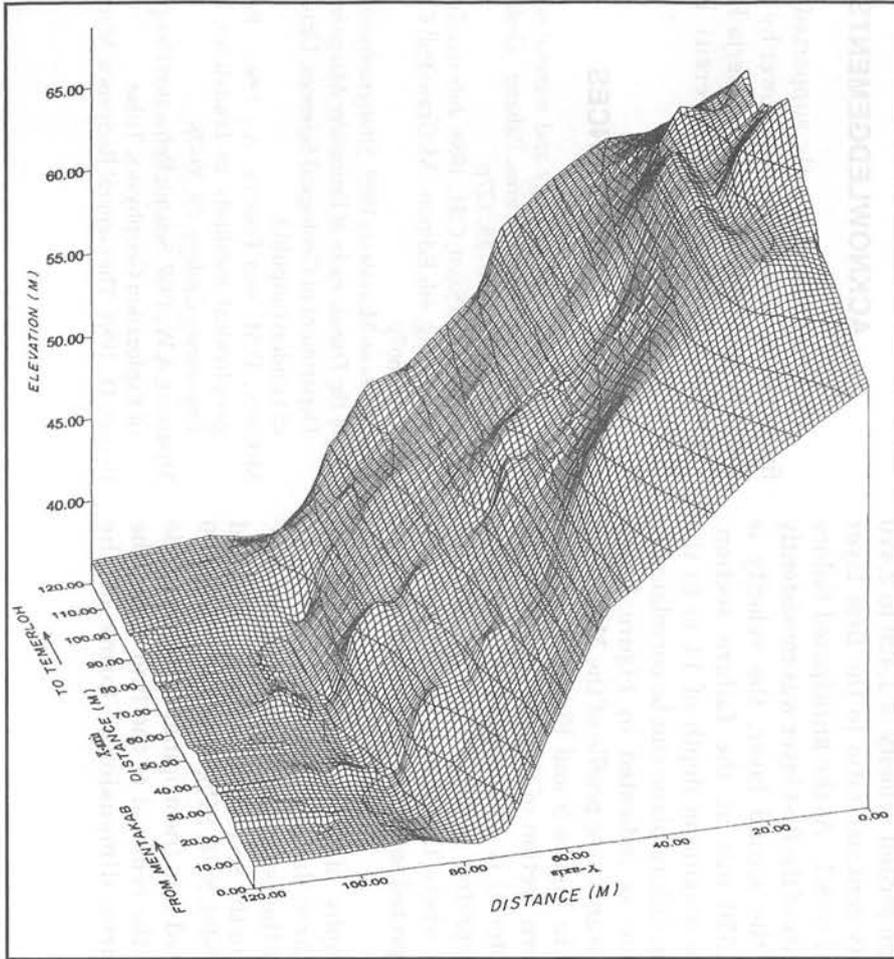


Figure 10. Post failure topography of the study area.

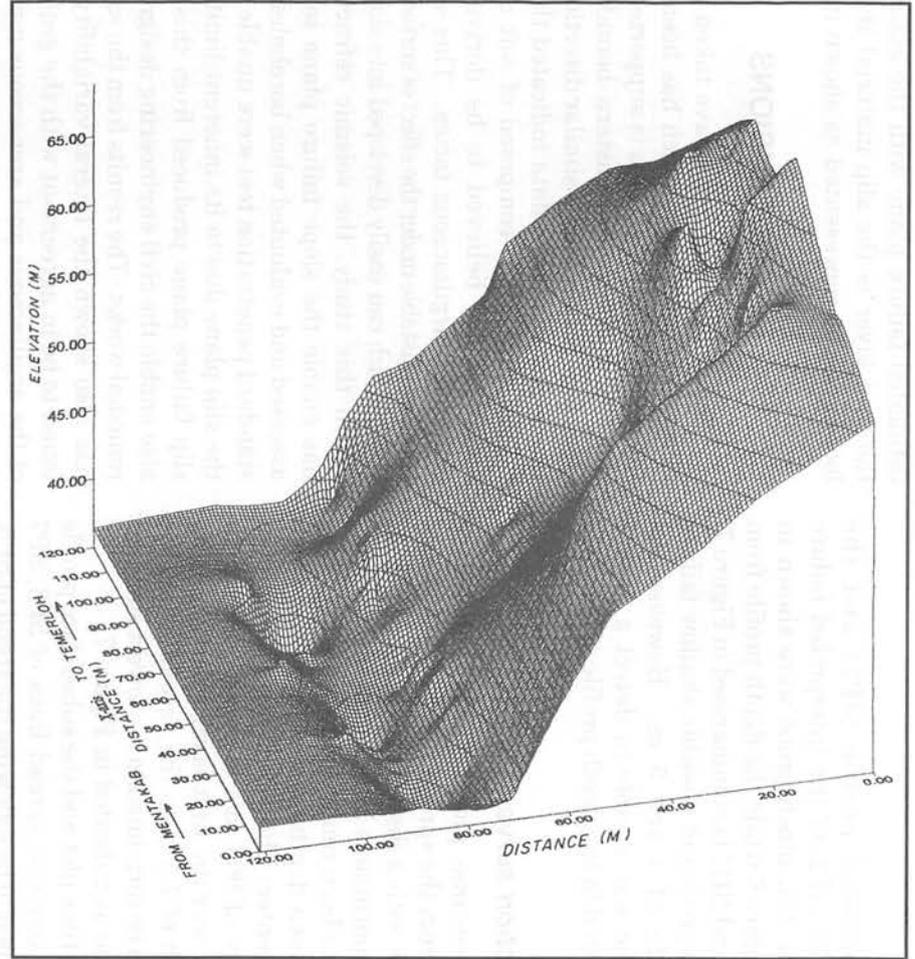


Figure 11. Representation of the failure surface with the first low velocity seismic layer removed.

Field tests

The longitudinal profile (JP1) and the transverse profile (JP2) of the interpreted failure surface from the Macintosh probe were shown in Figure 5 and Figure 6 while the depth profile from boreholes BH3 and BH4 is summarised in Figure 7. Both the tests were found possible shallow failure planes at depths of 4 and 5 m. However the Macintosh probe was unable to detect a deeper soft layer indicated in the depth profile of borehole BH4.

Seismic refraction survey

The distance-time plot and the subsurface profile (Fig. 8) from the spread line SP5 has shown a two layer case with a distinct first layer velocity indicated by a continuous initial high distant-time gradient that has been computed to be in the range of 334 m/s between depths of 3 to 7 metres which thickens at the center. The second layer interpreted to be at velocity of 903 m/s is considerably high with a 3:1 ratio over the first layer velocity. At its maximum depth of 7.5 m to the second layer, the failure plane can be correlated to the lowest standard penetration value as indicated in Figure 7.

The distant-time plot and the subsurface profile (Fig. 9) for the combine spread lines of SP6, SP7 and SP8 are shown to be following the trend of SP5. A distinct low first layer velocity of 310 to 496 m/s overlying a high second velocity of 1,420 to 2,470 m/s with velocity contrast ratio to the first layer ranging from 3:1 to 8:1. At the anticipated failure section the velocity of the first layer was consistently 496 m/s. For the second layer, the velocity is consistently 1,550 m/s at the failure section. Similarly, at its maximum depth of 14 m to the second layer, the failure plane can be correlated to a low SPT value as indicated in Figure 7 and confirms to the transverse profile of the Macintosh probe indicated in Figure 5 and Figure 6.

At the eastern section of the site at which the argillaceous material is present, the second layer velocity is interpreted to be 2,470 m/s. At the western section where the arenaceous material is found, the interpreted second layer velocity is found to be 1,420 m/s.

The topography of the ground level for the failure site in three dimensional form is given in Figure 10 using the perspective view from Surfer. With the depth to the second layer from the spread lines SP1, SP2, SP3, SP4, SP5, SP6, SP7, SP8, SP9 and SP10 inserted into the original surfer data file which result in the removal of the first layer, the graphically three dimensional forms of the

estimated failure plane with the assumption that the first layer is the slip material that had been loosen can be represented as shown in Figure 10.

CONCLUSIONS

The slope failure may have taken place at one of the anticlinal ridge which has been affected by the regional faulting. This is supported by the fact that the western and eastern boundaries of the slope failure had shown similar directions to that of the faults. The field data indicated that the slope failure material is composed of soft clay and silt and they are believed to be derived from the weathered argillaceous facies. This soft material becomes unstable under the effect of surface and ground water which can easily developed into slope failures.

In this study, the seismic refraction method has enable the slope failure plane to be initially assessed and evaluated when boreholes logging and standard penetration test were unable to represent the slip plane due to its inherent limitations. The slip failure plane produced from this survey will also enable the civil engineering design of the slope remedial works. The results from the seismic profile has also shown the lateral variability which was found to be in agreement with the geological facies of the argillaceous and arenaceous material which was found at the site.

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REFERENCES

- AHMAD J., 1976. The geology and mineral resources of the Karak and Temerloh area, Pahang. *Geological Survey of Malaysia Memoir*, 15, 127p.
- DOBRIN, M.B. AND SAVIT, C.H., 1988. *Introduction to geophysical prospecting*, 4th Edition. McGraw-Hill Company, New York, 867p.
- KAMAL ROSLAN MOHAMAD, 1989. *Stratigraphy and sedimentology of the Triassic rocks of Peninsular Malaysia*. Ph.D. thesis, Department of Geological Sciences, University College of London (unpubl.).
- MCCANN, D.M. AND FORSTER, A., 1990. Reconnaissance geophysical methods in landslides investigation. *Engineering Geology*, 29, 59-78.
- MUSGRAVE, A.W., 1967. *Seismic Refraction Prospecting*. Society of Exploration Geophysics, Tulsa.
- PALMER, D., 1980. *The General Reciprocal Method of Seismic*

- Refraction Prospecting. Society of Exploration Geophysicists, Tulsa.
- RIPEPE, M. *ET AL.*, 1990. Shallow depth seismic refraction for engineering site investigation — A solution by micro-ordinateurs. 6th International IAEG Congress, Sjorgren, 1984. Shallow refraction seismic, Chapman and Hall, London.
- TELFORD, W.M., GELDARL, L.P. AND SHERIFF, R.E., 1990. *Applied Geophysic*. Cambridge University Press, New York, 770p.

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