# Slope Stability Analysis at Hilly Areas of Kuala Lumpur, Malaysia

Ismail N. I., Wan Yaacob W. Z., and Ali N. A.

Abstract—Two case studies on landslide investigation were conducted on Kuala Lumpur slope areas. The purposes of the study are to characterise the subsurface conditions, to carry out slope stability analysis and to recommend suitable rectification works. A total of eight seismic refraction survey lines and 13 boreholes were carried out. A computer program 'SLOPE/W' was deployed by adopting a limit equilibrium method (LEM) to determine the factor of safety (FOS). The findings showed that the geophysical methods coupled with borehole and slope stability analysis were useful tools for the characterisation of slope failure. The seismic refraction survey results have provided information of weathering and rippability of the bedrock. Based on the analysis, the FOS were less than 1.5 which signify the inherently unstable slopes, thus, suitable remedial measures were proposed to improve the stability of the slope. The application of soil-nail will provide a reinforcing action to the soil mass, thereby increasing the stability of the slope.

*Index Terms*—Kuala Lumpur, slope stability, geotechnical, seismic refraction, slope/W.

## I. INTRODUCTION

Slope failure is a complex geohazard that has negative consequences on the environment and socioeconomic aspects. The increase cases of slope failure are associated with rapid infrastructure development and to hilly terrain, according to the study conducted by Hamzah *et al.* [1] and Zulfahmi *et al.* [2].

According to Petley et al. [3] and Marcato et al. [4], the investigation of slope failure usually requires boreholes to obtain information on the mechanical and hydraulic characteristics of the study area at a specific point of the subsoil. In order to overcome this problem, the application of the in-situ geophysical method has become a prime choice in providing continuous information which is incorporated on a greater soil volume besides offering a non-destructive method. Geophysical methods, particularly the seismic refraction (SR) method has been extensively used to encounter civil engineering problems in Malaysia such as pavement, geotechnical and environmental engineering according to Hazreek et al. [5]. A thorough study that is conducted by Israil and Pachauri [6] on the geophysical characterisation of a landslide site has stated that the seismic refraction can provide information on the behaviour of seismic refraction underlying the slope areas which is mainly controlled by the lithology, porosity and interstitial fluids of geomaterials.

Many researchers have performed a number of experiments in order to correlate P-wave velocities with SPT N values and borehole data at different sites (Aziman *et al.* [7]; Bery *et al* [8]; Pegah *et al.* [9]; Sarkar *et al.* [10]). Still, more efforts are needed to provide a wide range of local relations that is related to the site specific formations. For this research, two case studies have been conducted-one at the Hawthornden Schist (HS) and the second at Kenny Hill (KH) Formations slope areas, using the seismic refraction method.

In a tropical region such as Kuala Lumpur, most landslides were associated with soil slopes. Based on the study conducted by the Kuala Lumpur City Hall (DBKL) [11], a total of 1,740 slope areas in Kuala Lumpur have been detected and are categorised to be at a high risk of landslides. The study done by Elmahdy and Mostafa [12] showed that most cases of slope failure in Kuala Lumpur occur in hilly areas and steep slope. The crisis of slope failures due to rapid development process leaves impacts such as property damage and the loss of human life, as well as high slope repair cost.

The main purpose of this study is to produce the subsurface profile using the geotechnical and geophysical methods, to evaluate the slope stability in the study areas using the obtained data, and to propose suitable slope rectification works within this area.

# A. Basic Theory of Seismic Refraction

Prior to outlining the methodology used, it would be gainful to describe the basic theory of seismic refraction, the factor of safety and slope stability analysis. The seismic refraction method uses the propagation of seismic wave through the soil strata and rocks, and determines indirectly the velocity of wave propagation.

In this case, the Snell's law of light and phenomenon of critical incidence is the fundamental physics behind the seismic refraction method. Figure 1 shows Snell's Law and critical incidence where the velocity of the first layer is  $V_1$ , underlain by a second layer with a velocity of  $V_2$ .

The method consists of measuring travel time (first arrival or first break) of P-wave that is generated by an impulsive energy source which is detected and measured by geophones. The geophones near to the source detect direct waves, whereas the geophones that are placed beyond some critical distance detect the refracted waves first. The first arrival produces a time – a distance graph that is to be converted into a format of velocity variations with depth. The graph will be processed and interpreted accordingly using softwares.

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Fig. 1. Snell's law and refraction ray across two layers of velocities, V1 and V2 (Redpath [13]).

# B. Basic Theory of Factor of Safety and Slope Stability Analysis

In theory, a slope is stable as long as the factor of safety (FOS) is greater than one and slope movement commences if the FOS is 1.0 or smaller. A FoS can be defined as the ratio of the forces resisting movement (thus ensuring the slope stability) to those driving movement (thus threatening the slope stability), i.e. the ratio between the active and passive forces. The value over 1.0 indicates that the slope is considered stable, according to Panulinova and Harabinova [14].

There are different methods of slope stability analysis available to engineers. Slope stability analysis can be carried out by the limit equilibrium method (LEM) (Namdar) [15], the limit analysis method (Kumar [16]), the finite element method (Griffiths & Lane [17]) or the finite difference method (Soren *et al.* [18]). Among these, the LEM is one of the most popular approaches in slope stability analysis as it is simple to use and have the capability of solving a statically indeterminate problem. Baba *et al.* [19] and Duncan *et al.* [20] have stated that the Morgenstern-Price limit equilibrium method is an accurate method for any geometries and soil profile for the analysis of slope stability.

## II. GEOLOGICAL SETTING

Both study areas are located in hilly areas in Kuala Lumpur. These study areas are divided into several slopes based on their slope aspects. Generally, the first site study which is located in Hawthornden Schist Formation is a residential area while the second site study located in Kenny Hill Formation has a mixed topography of undulating valley, surrounded by authority buildings. Based on the geological map of Kuala Lumpur (Sheet 94) that is published by the Geological Survey Department of Malaysia, the general geology of the first site study was formed by Hawthornden Schist of Silurian- Ordovician age. The second site study is underlain by Kenny Hill formations according to Kuala Lumpur Geology Map which is published by the Minerals and Geoscience Department Malaysia [21] as shown in Fig.



Fig. 2. Geology of the study area.

# III. METHODOLOGY

In this study, the borehole drillings were conducted prior to the seismic refraction survey. Therefore, the alignment of seismic refraction lines was proposed based on the location of the boreholes. Fig. 3 to 5 show the boreholes and seismic lines that were conducted in the study area.

The seismic refraction survey conducted at Hawthornden Schist and Kenny Hill Formations slope involved three main stages, namely field surveys, data processing and interpreting data. Seismic refraction survey had been carried out to determine the nature of soil and rocks that were found in the study area.



Fig. 3. Location of boreholes seismic lines for Hawthornden Schist Fm. area



Fig. 4. Location of boreholes seismic lines for hawthornden schist fm. area.



Fig. 5. Location of boreholes seismic lines for kenny hill fm. area.

Eight lines of the refraction seismic survey were conducted in both study areas using an ABEM Terraloc MK3, 24 – channel seismograph with a 8-kg sledgehammer and 20 Hz-geophones spaced. This study applied two offset shots, two end shots, and three center shots for efficient processing. The seismic lines used 3 to 5 m of the geophone spacing interval. Using the Geometric Seismodule Controller & SeisImager (Pickwin & Plotrefa) software package and supported by borehole data,2D seismic refraction primary velocity results representing subsurface profile for each survey line were calculated. This is to determine time and depth of the investigated subsurface profile based on linear and delay time analysis. Thirteen numbers of boreholes were carried out using the Rotary Wash Boring Method at different locations of the slope failure areas. Standard Penetration Test (SPT) was conducted to determine the bearing capacity of the soil as described in BS1377. Disturbed and undisturbed soil samples that had been taken from the boreholes were used for physical and mechanical purposes in the laboratory.

A series of laboratory testing has been carried out to measure the engineering properties of the soil. The test results show that both study areas are dominated by sandy SILT soil. All the undisturbed samples have undergone the consolidation undrained triaxial test (CIU) to obtain the reference shear strength to evaluate the slope stability of the study areas.

Modeling of soil layer for investigated slopes was conducted using the seismic refraction interpretation. The seismic refraction results conducted were compared and correlated with those of previous researchers. The *Slope/W* program developed by GEO-SLOPE was deployed to evaluate the critical soil parameter obtained through back analysis. The analysis method adopted is Morgernstern – Price's method.

While stabilising the selected models, soil nails were used in order to modify the critical slip surface and to enhance the FOS against the slope stability failure. The soil nails used in this study had the following specifications as shown in Table I.

Property	Value
Length	12m
Inclination	20°
Pull out resistance	195kPa
Bond diameter	0.11m
Resistance Reduction Factor	3
Nail spacing	1.5m
Tensile Capacity	191.931kN
Shear Force	0kN
Shear Reduction Factor	1

#### IV. RESULTS AND DISCUSSION

#### A. Soil Properties

The borehole data showed that the subsurface soil profile at both study areas were not homogeneous. The hard layer in the Hawthornden Schist Formation area is starts at various depths from 2.0 to 13.5m meanwhile for Kenny Hill Formation, the soil profile starts at 5.0 to 16.0m depth. The soil sample that has been collected from Hawthornden Schist Formation study area consists of SILTY soil with low to high plasticity while the SILTY soil sample collected from Kenny Hill Formation has intermediate to high plasticity.

#### B. Seismic Refraction

Several results of seismic refraction for both study areas are given in Figure 6 and 7. The seismic refraction method has identified three main layers of velocity representing three types of geomaterials with possible different characteristics. Primary velocity ( $V_p$ ) value, as reported by previous researchers, are given in Table II while a summary of seismic lines configuration and findings are given in Table III, IV and V.

Description	Primary velocity,
	Vp (m/s)
Air [22]	331.5
Soil [23]	250-600
Sandstone [23]	1500-3000
Shale [23]	1200-3000
Hard rock [23]	Above 2400
Rock, weathered, fractured, or partly	610 - 3048
decomposed [24] and [25]	
Water [23]	1400 - 1600

TABLE II: TYPICAL PRIMARY VELOCITY (VP) OF SOME EARTH MATERIALS

For this study, the selections of 800 m/s and 1800 m/s as the lower and upper boundaries of rippable material in terms of seismic velocity are approximately borne out by the result of boreholes and the examination of the tomograms which form part of this investigation. The thickness of the specific layer varies, depending on the degree of weathering process.

The results for Hawthornden Schist Formation consist of

top soil/residual soil (<800 m/s) 3 - 16 m, weathered zone with a mixture of soil, boulder and rock fractured (800 1800 m/s) 4 - 22 m and rock/bedrock (> 1800 m/s) from 14 m depth. Meanwhile, the results for Kenny Hill Formation consists of top soil/residual soil (<800 m/s) 10 - 15 m, weathered zone with a mixture of soil, boulder and rock fractured (800 1800 m/s) 15 - 30 m and rock/bedrock (> 1800 m/s) from 30 m depth.

TABLE III: SEISMIC REFRACTION RESULTS FOR HAWTHORNDEN SCHIST AND KENNY HILL FORMATIONS

Classes of Material	Soil	Hard (rippable) material	Rock
Required method of fragmentation	Can be excavated	Can be ripped	Drilling and blasting
Velocity of seismic P wave (VP) (m/s)	<800	800 to 1800	> 1800
Borehole Criteria	SPT N < 50	SPT N > 50, No core recoverable	Diamond coring required, unconfined compressive strength >5Mpa
Field Criteria	Hard Layer	Extremely weak to very weak rock	Weak rock or stronger

TABLE IV: SEISMIC REFRACTION RESULTS FOR HAWTHORNDEN SCHIST FM

Slope	No of	Range of soil	Range of rippability
	Seismic Line	thickness(m)	material thickness (m)
В	Line 2	11 -16	13 - 22
С	Line 1	8 - 15	8 - 16
D	Line 3 & 4	3 -14	4 -13

TABLE V: SEISMIC REFRACTION RESULTS FOR KENNY HILL FM

Slope	No of Seismic Line	Range of soil thickness(m)	Range of rippability material thickness (m)
А	Line 1 - 4	10-15	15-30



Fig. 6. Result from seismic line of hawthornden schist fm.

# C. Slope Stability Analysis

Fig. 8 to 9 show the generalised soil profile at the Hawthornden Shcist and Kenny Hill study areas based on the results of seismic refraction and SPT. The summary of the back analysis parameters used to calculate the critical slip surface of the soil layer in terms of unit weight, angle of friction and cohesion are summarised for the purpose of evaluation as shown in Table VI and Table VII.

TABLE VI: CRITICAL SOIL PARAMETERS USED FROM BACK ANALYSIS FOR HAWTHORDEN SCHIST FORMATION

		Soil Parameter		
Soil Profile	N- SPT	Unit weight y	Cohesion,	Angle of
		(kN/m <sup>3</sup> )	c (kPa)	friction (°)
Layer I	0≤N≤5	17.0	2	30°
Layer II	7≤N≤21	18.0	5	32°
Layer III	29≤N≤41	19.0	7	35°
Hard Layer (IV)	N<50	19.5	10	35°

TABLE VII: CRITICAL SOIL PARAMETERS USED FROM BACK ANALYSIS FOR KENNY HILL FORMATION

		Soil Parameter		
Soil Profile	N- SPT	Unit weight	Cohesion,	Angle of
		$\gamma (kN/m^3)$	c (kPa)	friction (°)
Layer I	4≤N≤8	18.5	3	26
Layer II	13≤N≤19	18.5	5	30
Layer III	28≤N≤48	19.5	12	32
Hard Layer (IV)	N<50	20	15	32

The slope conditions were assessed in terms of factor of safety (FOS):

a) Slope stability analysis (back analysis)

b) Slope stability analysis (with treatment)

The existing slope models for Hawthornden Schist Formation and Kenny Hill Formation are shown as in Fig. 8 and Fig.10. The results show that the FOS is less than one (FOS = 0.56 for Hawthornden Schist Fm.) and (FOS = 0.98for Kenny Hill Fm.), which reflect the actual site condition of the failed adjacent slope, and the remedial work that needs to be installed to stabilise the slope.

Slope stabilisation measures are necessary for both study areas in reducing the probability of failure in the future. These slopes were analysed for appropriate and effective design in accordance to British Standard BS8006: 1995. Soil nail has been selected as the reinforcement measure to resist the additional shear forces from the imposed load and to intercept the slope failure plane.

The result in Fig. 9 and Fig. 11 indicate that with the application of 12 m length of soil nailing, the FOS generated by the SLOPE/W is 1.46 for Hawthornden Schist Formation and 1.89 for Kenny Hill Formation which is considered adequate for the reinforced slope according to the Malaysia Public Work Department guidelines [26]. Besides, this clearly shows that unstable slopes can be effectively reinstated to its stable condition with the adoption of soil nails.



Fig. 7. Stability of existing slope at hawthornden schist formation.



Fig. 8. Stability of slope at Hawthornden Schist Formation with the application of 12m soil nailing.



Fig. 9. Stability of existing slope at Kenny hill formation.



Fig. 10. Stability of slope at Kenny hill formation with the application of 12m soil nailing.

Further analyses provide the following results which have been carried out for three cross sections, namely CHS1, CHS2 and CHS3 for Hawthornden Schist Formation area and CKH1 and CKH2 for Kenny Hill Formation area, respectively. The result of the stability analysis is tabulated in Table VIII and IX below.

TABLE VIII: SUMMARY OF SLOPE STABILITY ANALYSIS IN HAWTHORNDEN SCHIST FM. AREA

Section	Existing Slope(FOS)	FOS Based on PWD	Remedial Works
CHS1 - CHS1'	0.564	>1.5	
CHS2 – CHS2'	1.114	>1.5	Soil Nail, Concrete Spray, Drainage
CHS3 – CHS3'	1.378	>1.3	

TABLE IX: SUMMARY OF SLOPE STABILITY ANALYSIS IN KENNY HILL FM. AREA

Section	Existing Slope(FOS)	FOS Based on PWD	Remedial Works
CKH1 – CKH1'	0.988	>1.5	Soil Nail, Concrete
СКН2- СКН2'	1.198	>1.5	Spray, Drainage

## V. CONCLUSION

Slope failure in the two slope areas of Kuala Lumpur has been presented as case studies to show that the resultsestablished through the method of geotechnical, geophysical and slope modeling, really covers all aspects in order to avoid the occurrence of slope failures and are useful tools for the slope failure investigation.

Based on the result of seismic refraction combined with slope stability analysis, the assumptions of subsurface profile can be reduced and can give confidence to the engineers. Moreover, the seismic refraction method could be implemented to investigate the failure of wide areas with a minimum number of borehole drillings.

Analysis of slope stability is very important to protect the slopes from failure and to minimise the possibility of slope failure. Evaluation on slope stability should be carried out to examine the design of the soil nail to ensure an improvement in the FOS of the slope. Through this, the stability of the slope can be assured and disastrous events can be prevented.

A reliable result was obtained throughout this study from the geophysical, geotechnical and slope modelling methods. The findings of this study showed that the geophysical method coupled with borehole drillings and slope stability were useful tools for the characterisation of slope failure via subsurface profiles and engineering properties of soil and could be used as guidelines for the investigation of similar slope conditions. Recommendation for future work will involve development of groundwater flow modelling by using a computer program 'MODFLOW' to provide information about the hydrogeological regime in the Kuala Lumpur study areas.

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