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Integration of Seismic Refraction and Laboratory Testing for Slope Stability Examination

Rohayu Che Omar[#1], Rasyikin Roslan[*2], Intan Nor Zuliana Baharuddin[#3], Hairin Taha[#4]

[#1,2,3,4] *Institute of Energy Infrastructure, Universiti Tenaga Nasional, 43000 Kajang, Malaysia*

[1]Rohayu@uniten.edu.my

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Abstract:
The application of geophysics survey mainly seismic refraction method has been limited to the area of study particularly in slope stability analysis. Standard methods of geotechnical investigation using boreholes and laboratory test results have been the most efficient technique in providing the geotechnical data for slope stability study. In some cases, however, where the slope area is located at higher ground with restricted access, an alternative method should be considered to replace the conventional methods as it is not applicable due to energy and timing constraints and higher operating cost. The objective of this study was to integrate seismic refraction method with laboratory test to produce general classification of slope stability status based on the relationship between slope Factor of Safety (FS) with soil modulus generated from the seismic refraction method. Prior to that, justification of soil modulus from the seismic refraction survey was first made in reference to the soil modulus obtained from the laboratory test before establishing the general classification. The results showed that the three soil parameters obtained from both methods were similar with percentage error ranging from 8% to 15%. It can be concluded that this method is more economical and applicable for slope stability analysis.

Keywords: *slope stability; seismic refraction; factor of safety; laboratory test*

I. INTRODUCTION

In the past, research engineers have adopted the usage of laboratory testing for slope stability analysis to obtain information regarding slope safety in the form of Factor of Safety (FS) [1]. This technique has yet to become a common method in producing reliable result to verify the stability status of the concerned slope. The term 'safe slope' is very subjective depending on the usage of the slope itself and as to why it is built. Slope area which is subjected to high loading from high rise building, will require higher FS as to minimize probability of slope failure occurrence [2]. For the case of natural slope, the minimum FS that a slope can be considered as safe slope is 1 whereby mitigation of slope can be omitted [3]. Conventional method using laboratory testing to determine slope FS, is time consuming for slope situated in hilly terrain area. Undisturbed soil sample is required to determine FS which unfortunately may only be obtained by using borehole. In hilly terrain area, access will be difficult for the boring machine including time and cost for mobilization, boring and demobilization that need to be considered.

Seismic refraction method of geophysical survey can augment the conventional geotechnical investigation at the slope area to obtain the parameters needed for slope stability analysis with

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comparison to laboratory testing [4]. Result from seismic refraction method will provide details of slope strata or sub-profile which is evaluated based on the relationship between compression wave (P-wave) towards depth of slope area. In addition to that, soil parameters of shear modulus, bulk modulus, Young's modulus and Poisson's ratio can be obtained by applying formula from Table 1 which highly dependent on the value of compression velocity, Vp, and shear velocity, Vs [5].

When these parameters are obtained from seismic refraction survey, comparison will be made with the same parameters which are determined from laboratory testing. The laboratory tests include undrained unconsolidated (UU) triaxial test, direct shear box test, dry and wet sieve analysis test and Atterberg's limit test. Undisturbed sample should be taken from the site area to ensure that the samples from the study area resemble its original characteristics. Where vehicular access is limited, machinery like hand auger can be used to obtain disturbed soil samples at depth of at least 2m. This is required in order to increase the accuracy of laboratory testing as soil layer above 2m depth might not be the original soil layer due to weathering and soil erosion. If sample is taken within new deposited soil layer from other sources, result yields through laboratory test will not match the characteristics of original soil from the study area in terms of parameters needed for slope stability analysis.

Concerned parameters obtained from the laboratory tests and seismic refraction surveys need to be acquired. Further analysis will be conducted by using the same samples for laboratory test to obtain FS for the slope in consideration. The relationship between slope FS with the value of Young's modulus, shear modulus and bulk modulus from the results can be established to provide slope stability status [6] . Finally, general classification of slope FS will be based upon the values of the above three modulus that were developed. However it requires few more benchmark data at different site areas to ensure that this technique can be applied to a wide range of slope type with varying soil types and characterizations.

TABLE 1

SOIL PARAMETERS OF SHEAR MODULUS, BULK MODULUS, YOUNG'S MODULUS AND POISSON'S RATIO

Soil parameters	**Formula**
Poisson's ratio	$\frac{1[\left(\frac{V_p}{V_s}\right)^2 - 2]}{2[\left(\frac{V_p}{V_s}\right)^2 - 1]}$
Young's modulus	$\frac{V_s{}^2 p[3\left(\frac{V_p}{V_s}\right)^2 - 4]}{g[\left(\frac{V_p}{V_s}\right)^2 - 1]}$
Bulk modulus	$\frac{V_s{}^2 p}{g}(\frac{V_p{}^2}{V_s} - \frac{4}{3})$
Shear modulus	$\frac{E}{2(1+u)}$

II Methodology

A. Seismic Refraction Method

Seismic refraction is based on the first arrival of a signal that travels through a layer with a higher velocity [7]. Table 2 gives some characteristic seismic P-wave velocities for sub-surface materials. The equipment used for this survey includes 24 channels ABEM Terraloc Mark 6 (Figure 1), geophones for S-wave and P-wave and hammer. Normally, geophones used for this survey have the frequency of 14 Hz. The travelling waves will be refracted based on the difference of soil layer before reaching the geophones. Source of elastic wave of type P is generated by the blow of hammer towards steel plate that is buried 3-5mm into the ground [8].

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TABLE 2
CHARACTERISTIC OF P-WAVE VELOCITIES

Material	P-wave velocity (m/s)
Air	360
Dry sand	400-1000
Clay	300-1800
Weathered igneous and metamorphic rock	450-3700
Weathered sedimentary rock	300-3000
Metamorphic rock	1000-6000
Unweathered basalt	1000-4300

For geophones located nearby the hammer source, the signal wave will travel directly to the geophones whereas for geophones located far away from the hammer source, the wave is more likely to be refracted before reaching the geophones. For an inclined plane boundary the survey should be repeated with the source position at the other end of the geophone spread. To generate S-wave, a wooden block of 2m length will be placed parallel to the shooting point and the hammer will be blown onto both of the block edges. During blowing session of hammer to detect S-wave or P-wave, any movement should be avoided to minimize error as geophones can be triggered by as small as walking motion.

This step should be taken into account for each hammer blow in order to avoid large error in the survey results. The survey line location should be maintained at an area with slope less than 30^{o}. Other conditions considered in the placement of survey line (geophones orientation) would include the availability of vegetation, landslide and soil erosion occurrence, scar orientation as well as the location of water table or groundwater.

Fig. 1 ABEM Terraloc Mark 6

B. Laboratory test

Soil samples collected of either disturbed or undisturbed sample was further analyzed using laboratory test to define required soil parameters for slope stability analysis. The types of laboratory test commonly used in Malaysia to determine soil classification, chemical and mechanical properties are summarized in Table 3. The total stress strength parameter undrained shear strength, S_u is required for short term undrained stability analysis of embankment on cohesive soils and for foundation design (e.g. footing, pile, retaining wall) in cohesive soils. The effective strength parameters like c' and f' are for long term stability analysis of foundation, embankment and slopes, particularly cut slopes.

III RESULTS AND DISCUSSION

A survey comprised of seismic refraction and application of resistivity has been carried out at the Temenggor-Pergau transmission line which was located on high hill area. The result from the resistivity imaging showed that the study area was mainly covered by shale, slate and sandy silt of metamorphic rock which may be due to long term effect of weathering and deposition of soil (Table 4).

Geophones orientation line for seismic refraction survey consisted of 2 lines which were C-C' and D-D' with total length of each line of about 46 m and geophone spacing of 2 m for 23 intervals of 24 geophones. A total of 5 hit points have been considered for the measurement along the both lines. The shot point (SP) was arranged to be as following:-

- SP1 and SP5 at 1 meter of the end of the line.
- SP3 at centre of the line (between geophone no.12 and 13)
- SP2 and SP4 at the quarter of the line (between geophone no.6 and 7, counted from both end of the line)

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TABLE 3

SOIL CLASSIFICATION TESTS & TEST FOR CHEMICAL AND MECHANICAL PROPERTIES

SOIL CLASSIFICATION TEST	TEST FOR MECHANICAL PROPERTIES
1. Particles Size Distribution : - Sieve Analysis (for content of sand and gravels) and Hydrometer Tests (for content of silt and clay)	1. One Dimensional Consolidation Test (Oedometer Test) :- to obtain compressibility and consolidation parameters for settlement analysis.
2. Atterberg Limits :- Liquid Limit, Plastic Limit & Plasticity Index (to be used in Plasticity Chart for soil classification)	2. Shear Strength Test : (a) For Total Stress :- Laboratory Vane, Unconfined Compression Test (UCT), Unconsolidated Undrained Triaxial Test (UU), Shear Box Test. (b) For Effective Stess :- Isotropic Consolidated Undrained Triaxial Test (CIU), Isotropic Consolidated Drained Triaxial Test (CID). (Note : Side Drains shall not be used on samples to accelerate consolidation to prevent errors) (Gue (1984) and Tscheboutarioff (1951))
3. Moisture Content	
4. Unit Weight	
5. Specific Gravity	
CHEMICAL TEST	
1. pH Test	
2. Chloride Content Test	
3. Sulphate Content Test	
4. Organic Content Test	3. Compaction Test

TABLE 4

RESISTIVITY IMAGE OF STUDY AREA

Data Name	Layer	Depth (m)	Colour	Specific	Resistivity (ohm.meter)	Geological Interpretation
TDDGP	Layer 1	1.05	Yellow		480-598	Shale / Clayey Boulder
	Layer 2	2.01	Dark Purple		1604-3500	Slate / Shale / Sandy Soil
	Layer 3	2.75	Purple		3500-5000	Slate / Sandy Soil
	Layer 4	3.95	Red		1300-1604	Slate / Shale / Sandy Soil
	Layer 5	5.10	Orange		979-1300	Slate / Shale / Sandy Soil
	Layer 6	5.95	Brown		750-979	Slate / Shale / Sandy Soil
	Layer 7	6.46	Dark Brown		598-750	Shale / Slate / Sandy Soil
	Layer 8	4.10	Yellow		480-598	Shale
	Layer 9	5.05	Green		365-499	Shale / Clayey Boulder
	Layer 10	3.05	Dark Green		298-365	Shale / Clayey Boulder
	Layer 11	4.04	Light Green		223-298	Shale / Clayey Boulder
	Layer 12	4.68	Blue Green		180-223	Shale
	Layer 13	6.46	Light Blue		136-180	Shale / Silt
	Layer 14	1.08	Blue		1.0-100	Clay / Groundwater / Silt

Figure 2 shows the time versus distance of two shot point which are SP1 and SP5 for line D-D'. Three segments for each shot point were predicted and for every segment, the velocity was calculated by inversing the slope value of each segment. Every segment gives a different velocity. Figure 3 shows the soil profile along the line D-D' based on the difference of seismic velocity obtained through the seismic refraction survey.

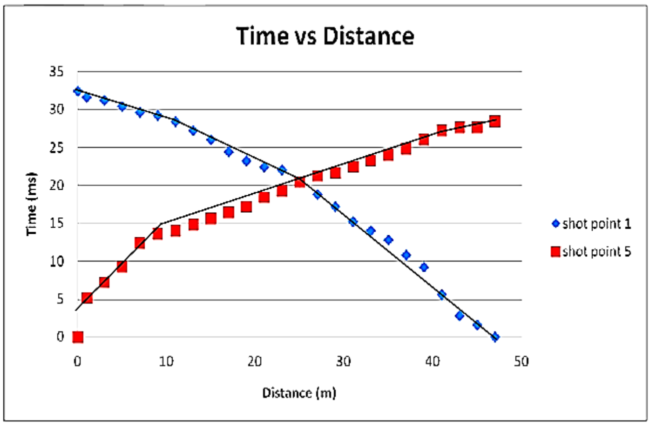

Fig 2. Travel time versus distance

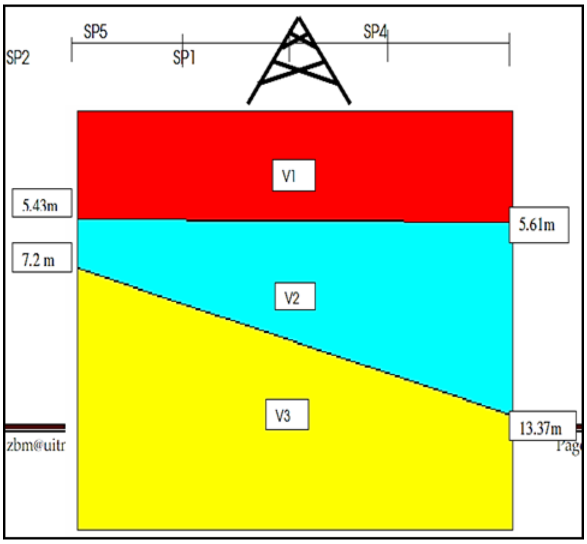

Fig 3. Soil profile at line D-D'

Different seismic velocities due to elasticity of soil materials provide details of different soil layers existed on the line D-D'. Table 5 shows velocity for each shot point of hammer to trigger seismic wave. Based on this result, the soil on the area may be divided into 3 main layers which are:-

- First layer, v1 < 1000 m/s, sp3 and sp4 are on weathered granite. Sp1, sp2 and sp3 are on fractured granite.
- Second layer, velocities of v2 are uniform at about 2000 m/s, probably fractured granite
- Third layer, v3 > 2000 m/s, slightly fractured granite

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TABLE 5
VELOCITY OF EACH SHOT POINT OF HAMMER

Location: Gerik line D-D’					
	sp1	sp2	sp3	sp4	sp5
v1 (m/s)	1033	1103	448.4	465.1	1028
v2 (m/s)	1845	2110	2198	1808	2320
v3 (m/s)	3049	-	-	-	2320
v4 (m/s)	-	-	-	-	-
Z1(m)	5.61	2.55	1.76	2.18	5.43
Z2(m)	7.76	-	-	-	1.75
Z3(m)	-	-	-	-	-

Disturbed soil sample was taken from line D-D’ for laboratory test purposes. The type of test conducted for this sample would be as follows:-

- Unconsolidated undrained (UU) triaxial test.
- Direct shear box test
- Atterberg’s limit test
- Sieve analysis test

The result showed that the cohesion, c and angle of internal friction, θ of respective soil sample were 10 kN/m^2 and 50.73°. The general classification of slope stability was established based on the value of Young’s modulus, shear modulus and bulk modulus obtained from both seismic refraction survey output and laboratory test and comparison were made to justify their similarities. The results of the comparison between the values obtained from Laboratory Test and seismic refraction survey are shown in Table 6.

TABLE 6

SOIL PARAMETERS FROM LABORATORY TEST AND SEISMIC REFRACTION SURVEY

Soil parameters	**Laboratory Test (kN/m^2)**	**Seismic Refraction Survey (kN/m^2)**
Young’s modulus, E	2512	2264.82
Shear modulus, G	1510	1293.92
Bulk modulus, K	626.5	539.4

The results showed that the three soil parameters obtained from both methods were similar with percentage of error 8% to 15%. It is expected that the result for both methods will not correlate exactly for these three parameters. It is because the deformation behaviour of most soil and rock masses depends on frequency and is non-linear. The frequencies in seismic waves are normally not the same as frequencies used in dynamic testing important the stress and strain in seismic waves are smaller compared to stress and strain in laboratory or field tests.

The next process was to define slope stability in terms of slope FS which will be based on data from laboratory test. The aim is to differentiate between ‘safe slope’ and slope with high probability of failure occurrence. In this case, safe slope will have FS of at least 1 and slope with failure probability will have FS of less than 1. General classification is to be made based on this criterion whereby parameters involved would include Young’s modulus, shear modulus, bulk modulus and obviously slope FS. However, more data are required to establish this general classification table as to ensure it efficiency as alternative of slope stability analysis by using seismic refraction method instead of conventional method.

V CONCLUSION

In order to establish the classification table for slope stability status, few more comparison are required as to ensure that wider range of soil parameters (Young's modulus, shear modulus, bulk modulus) and slope FS are to be taken into account. In advance, development of slope FS classification table based on data from seismic refraction method can become alternative way for research engineers to determine slope stability of an area without using conventional method especially on high hill area with access restriction. The application of geophysical survey using seismic refraction method can save time and energy, and most importantly, the operating expenses for slope stability investigation can be reduced significantly.

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