Integrated Methods of Geophysical and Geotechnical Study on Saturated Ground Profile

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Abstract: Subsurface geophysical study was performed in SK Seri Molek, Batu Pahat-Johor, using seismic refraction of compressional wave method which calibrated to field exploration of soil boring. The main objective of this study is to produce and discuss the seismic tomography profile in conjunction with bore log data on saturated ground stratification. ABEM Terraloc MK 6 seismograph with 24 units of 28 Hz vertical geophones was used in data acquisition process. For the processing and analyzing tool, OPTIM software was adopted in this study. Two spread lines of seismic refraction were provided parallel to the borehole positions with 4 meter geophones spacing at 40 meter offset on spread line 1, and equal spacing but 50 meter offset was applied on spread line 2 due to unavoidable obstacle. From the results, multiple layers based on significant contrasts of P-wave velocity have been clearly shown in both spread line profiles. About 20 to 30 meter depth able to be archived in the seismic survey while from the site investigation report the boreholes have been terminated when it reached to 30 meter depth. In overall, good agreements between both integrated methods were concluded from the results obtained with slight difference in terms of soil classification at B and C layers in spread line 2. Some discussions also being touched on the influence of low ground water level to the ground stratigraphic that may affect to the accuracy and misinterpretation on soil material type and classification.

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Keywords: Seismic refraction, borehole, P- wave velocity,

1. Introduction

Seismic refraction survey is widely used due to its simplicity, cost-effective and non-destructive in sub-surface profile investigation. This geophysical method may give a quick prediction in two dimensional perspective of soil profile based on its dynamic parameter values of P-wave velocity represented by the soil/ rock layers underneath the ground surface up to 30 m to 40 m depth. Conventional destructive method of a borehole is quite limited to a specific point and small radius of site coverage. However, an integration of both methods may enhance to better findings in subsurface investigation to a bigger cross section output that very useful in planning and foundation design perhaps able to predict for any existence of ground uncertainties [1,2].

In this study, an integrated methods of geophysical and geotechnical survey was carried out at SK Seri Molek, Batu Pahat-Johor, Malaysia. Historically, the first building in this school was constructed in October 1976. According to geological formation of 1985 map given in Figure 1 [3], the location of this school is estimated underlying on the boundary of unconsolidated soil deposits classified in Quaternary zone and intrusive rock. In addition to the recent bore log data from field exploration conducted by IKRAM group in January 2008, the soil deposit may be considered in saturation condition due to low ground water level at 0.40 m from the ground surface [4]. Since, the effectiveness of geophysical methods largely depend upon the presence of a significant and detectable contrast in the physical properties of different lithological units as the seismic P-wave velocity are normally affected by density, lithology, porosity, lithification, pressure, fluid saturation and anisotropy of the geo-materials [5], this study may give some understanding on the influence of saturated subsoil condition to the seismic refraction (P-wave velocity) from the geophysical survey conducted.

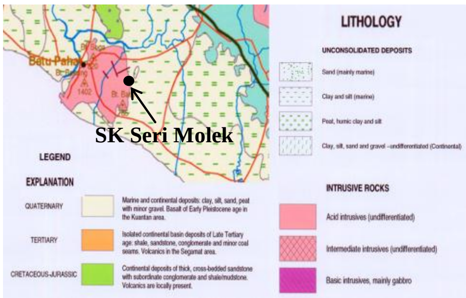


Figure 1: Geological Map of Study Area [3].

2. Seismic Refraction Survey Methodology

Generally, this section explains on the adopted procedures of seismic refraction survey including the field instruments, processing tools and analyses involved in prediction of subsurface soil profile. Prior to the discussions of result, the methodology of this study consists of three main phases and they are, desk study (focusing into data collections) followed by data acquisition (fieldwork) and data processing using conventional software of OPTIM (analysis) as illustrated in Figure 2.

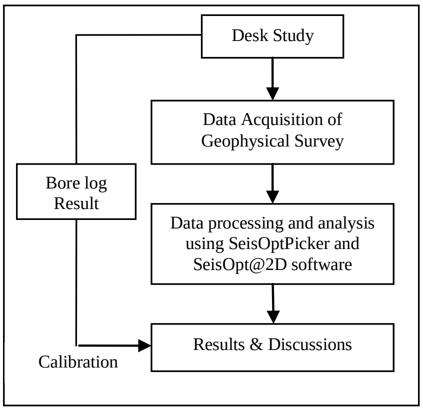


Figure 2: Study Flowchart

ABEM Terraloc MK-6 seismograph was employed in this study. It consists of three main equipment components which are seismic source, detector and data logger. A sledge hammer of 7 kg weight was used to trigger the waves in soil/ rock medium. For detectors, 24 vertical geophones of 28 Hz were laid at 4 meter spacing. Two spread lines were prepared as in the layout plan of Figure 3, with 40 m offset for spread line 1 and additional 10 m length for spread line 2 on both sides as given in Figure 4. Difference offset was due to space limitation. By referring to similar figure, seven shot points were taken on the first offset point, then moved on the middle of geophones 1st and 2nd, 6th and 7th, 12th and 13th, 18th and 19th, 23rd and 24th, and finally ended on the last offset point with minimum of 15 shots per each shot point. The sensitivity of sensors was adjusted to an appropriate noise level from the seismograph control panel. Besides, a strict controlled to external noises disturbance such as transient, extreme weather, nearby structure such as trees, monotonic sources etc. were also considered. The refracted energies were detected when the seismic waves travelled into different soil/ rock layers from each shot given. Multiple stacking was applied to obtain a good signal quality of the first wave arrival of compressional wave (P-wave).

When it comes to data processing and analysis, the measured seismic signals were processed using OPTIM software. OPTIM software is consists of SeisOptPicker that function as a processing tool in identification of P-wave, and the processed P-wave signals were exported to SeisOpt@2D in order to generate tomography of subsurface soil profile.

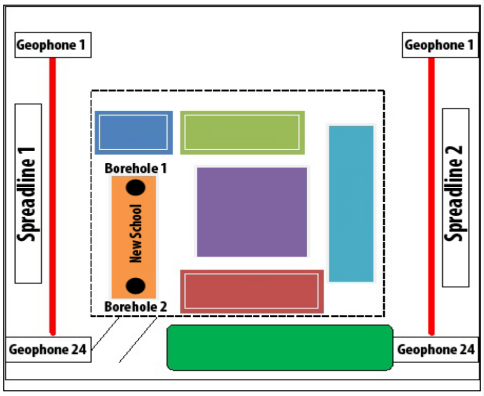


Figure 3: Spread lines Layout and Positions of Borehole

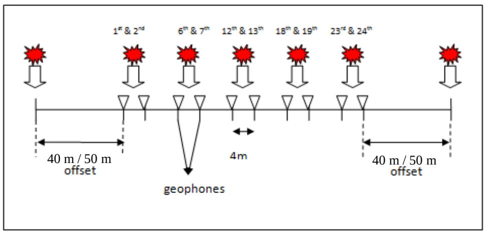


Figure 4: Shot Points Position

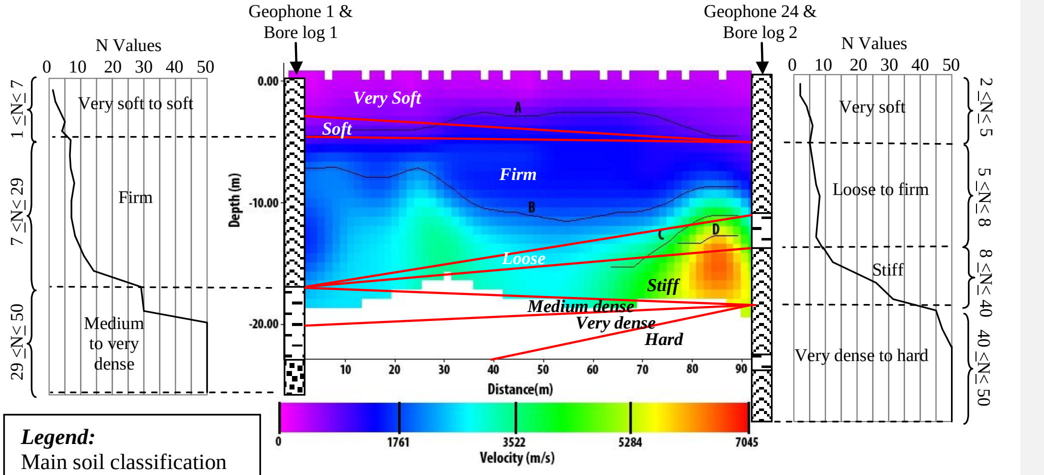
3. Results and Discussions

Comparative results from both geotechnical and geophysical subsurface profiles were presented in Figure 5 and 6. Borehole profile and its soil classification, SPT (Standard Penetration Test) curve and soil scales based on the N values, were extracted from the site investigation report obtained. Meanwhile, multiple boundary layers of soil/ rock have been identified with its P-wave velocity via analyses conducted using OPTIM software.

A good agreement was given by spread line 1 between both integrated methods used. By referring to Table 1, the first three prediction layers of soil/ rock may be classified as loose to soft, moderate stiff and very stiff based on P-wave velocities of 875 to 940 m/s, 1852 to 1923 m/s and 3544 to 4030 m/s. This classification was made using Table 2.

Comment [h1]: Please add some appropriate seismograph setting/acquisition setup in order to determine a good/clear trace signals which related this study based on its ground condition (e.g. reco length, sampling interval, no of samples. etc)

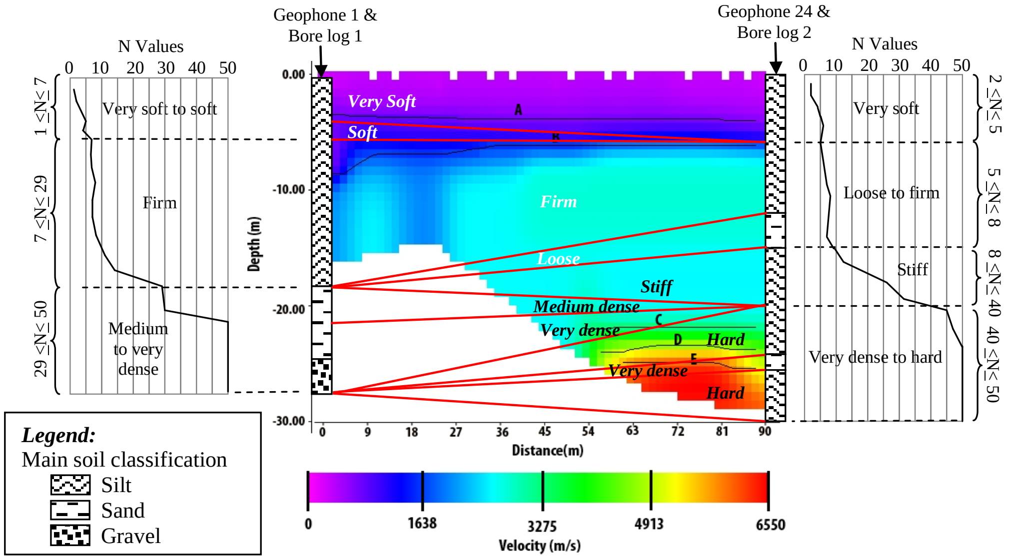
Answer: Record length, sampling interval and no samples are not influenced the noise level. Theref it were not discussed in this paper.



Layer	Boundary depth (m)	P-wave velocity (m/s) at boundary
A	2.7 - 4.4	875 - 940
B	7.8 – 9.8	1852 - 1923
C	11.0 - 15.4	3544 - 4030

Refer to Table 2:
Loose and soft
Moderate stiff
Very stiff

Figure 5: Integrated Results of Geophysical (Spread line 1) and Geotechnical Testing (Borehole 1 and 2)



Layer	Boundary Depth(m)	P-wave velocity (m/s) at boundary
A	3.13 – 3.31	615 - 684
B	5.67 - 6.31	1626 - 1949
C	21.29 - 21.38	3241 - 3284
D	23.28 - 23.46	5004 - 5200
E	24.37 – 24.74	5660 - 5772

Refer to Table 2:
Loose and soft
Moderate stiff
Very stiff
Hard

Figure 6: Integrated Results of Geophysical (Spread line 2) and Geotechnical Testing (Borehole 1 and 2)

Table 1: Summarized Result from Figure 5

Soil layer	Predicted depth from seismic test (depth from borehole record)	P-wave velocity (m/s)	Soil/ rock classification based on N values in bore log		Soil/ rock classification based on [4]
			Bore log 1*	Bore log 2**	
A	2.7 - 4.4 (5m * & **)	875 – 940	Very soft to soft	Very soft	Loose and soft
B	7.8 – 9.8 (5 to 18m*) (5 to 12m**)	1852 – 1923	Firm	Firm	Moderate stiff
C	11.0 - 15.4 (18 to 21m*) (12 to 20m**)	3544 – 4030	Medium dense	Loose to stiff	Very stiff

Table 2: Classification of Soil and Rock based on P-wave Velocity (V_p) by [4]

Soil and rock type	V_p (m/s)
Hard and massif rocks	6000-4200
Very stiff	4200-3000
Stiff	3000-2000
Moderate stiff but altered	2000-1500
Loose and soft	1500-600
Soft and saturated	>1300

Low level of ground water may influence to the accuracy of P-wave velocity of saturated materials that approximately exceed 1300 m/s, as stated in Table 2. It has long been recognized that compressional waves in contrast to shear waves (S-wave) that, the propagation of the velocity in saturated soils is strongly affected by the water filling the interstices of soil grains [6]. This circumstance could cause to misinterpretation of soil/ rock class including to its materials type since it could be in any groups of harder material due to high P-wave velocity value (refer to Table 3). Application of horizontal or smaller frequency of vertical geophones (i.e. 4.5 Hz) could be recommended in determining S-wave velocity for soil characterization in saturated strata by seismic refraction survey for better prediction accuracy [7].

Meanwhile, in spread line 2 findings, two significant contrasts may observe between B and C layers as shown in Figure 6. Higher P-wave velocities were indicated when approaching to geophone 24. The prediction of soil/ rock classifications via seismic prediction and bore hole result were slight different in similar layers, but a good agreement given in D and E layers. Further distance of borehole points to spread line 2 probably has changed the formation of underneath ground profile in between, compared to the spread line 1 that more closer. Further calibration of in-situ test is recommended to be done in order verify to this seismic finding.

Table 3: P-wave Velocities for Various Type of Soil and Rock [8]

Materials	V_p (m/s)
Weathered surface material	240 to 610
Gravel or dry sand	460 to 915
Sand (saturated)	1220 to 1830
Clay (saturated)	915 to 2750
Water	1430 to 1665
Sea water	1460 to 1525
Sandstone	1830 to 3960
Shale	2750 to 4270
Chalk	1830 to 3960
Limestone	2134 to 6100
Granite	4575 to 5800
Metamorphic rock	3050 to 7000

Table 4: Summarized Result from Figure 6

Soil layer	Predicted depth from seismic test (depth from borehole record)	P-wave velocity (m/s)	Soil/ rock classification based on N values in bore log		Soil/ rock classification based on [4]
			Bore log 1*	Bore log 2**	
A	3.13 – 3.31 (4m* & **)	615 - 684	Very soft	Very soft	Loose and soft
B	5.67 – 6.31 (4 to 5m*) (4 to 5m**)	1626 - 1949	Soft	Very soft	Moderate stiff
C	21.29 – 21.38 (5 – 21m*) (5 to 20m**)	3241 - 3284	Firm to medium dense	Loose, firm to stiff	Very stiff
D	23.28 – 23.46 (21 to 27m*) (20 to 24m**)	5004 - 5200	Very dense	Hard	Hard
E	24.37 – 24.74 (21 – 27m*) (24 to 30m**)	5660 - 5772	Very dense	Very dense to hard	Hard

4. Conclusion

A geophysical study of seismic refraction survey in SK Seri Molek, Batu Pahat-Johor has shown a good agreement of subsurface profile prediction with some calibration also be made to the bore hole data obtained. The site was considered in saturation and careful analysis should be emphasized since the P-wave velocity is prone to be affected by the existence of water in soil. It is also recommended to perform different approach of refraction technique by applying the horizontal or vertical geophone with smaller frequency for convincing result. Finally, the geophysical method of seismic refraction in conjunction with conventional approach of in-situ soil boring test, may able to delineate the stratigraphic of a site with detailed

Comment [h3]: Please state some specific typ of recommended in situ test.

Answer: In situ test using controlled soil variable (such as layer thickness, layer density, moisture content, soil type) is recommended for future stud

Comment [h2]: Please justify some reason wh this proposed method was recommended.

Answer: S-wave velocity in water in 0 m/s, meanwhile p-wave velocity in water was 1450 m/ Therefore combination of p and s-wave are recommended to differentiate the soil saturated strata.

subsurface profile images even provide a bigger perspective of ground investigation.

5. Acknowledgment

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6. Referrence

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Comment [h4]: Please add more related literature/references in order to strongly support t study.

Answer: We add another 2 references