2D Seismic Refraction Tomography Survey on Metasediment at a Proposed Development Site in Dengkil, Selangor

Umar Hamzah and Abd Rahim Samsudin

Program Geologi, Fakulti Sains & Teknologi
Universiti Kebangsaan Malaysia

Abstract: A geophysical survey using seismic refraction technique was carried out at a proposed development site at MINT-Dengkil. The aim of the study was to characterize the subsurface materials based on seismic P-S wave velocities as well as to correlate those data with the lithologic logs and the standard penetration test (SPT) N-values. The study area is about 40 km squares, consisting of shale, slate and siltstones of the Kenny Hill Formation. Seismic surveys were carried out using ABEM MK 3 as a recording seismograph, and 24 units of 14Hz-frequency geophones 'to record the incoming seismic waves. The data were processed using an OPTIM software to produce sections of 2D velocity model profiles. Results show P-wave velocity of clayey silt (SPT=3-11) is ranging from 300-500m/s and S-wave velocity is ranging from 80-100m/s. P-wave velocity value for sandy silt (N=12-16) is ranging from 500-800m/s and S-wave velocity is found ranging from 100-300m/s. P-wave velocity value representing hard silt with gravel (N=20-50) is ranging from 900-1600m/s and S-wave velocity is ranging from 300-450m/s. The S-wave velocity obtained from seismic surveys show only slight difference in values compared with those calculated using SPT N values. The calculated Poisson ratio value ranging from 0.43-0.47, representing clayey-silt and sandy-silt. Velocity model sections were correlated well with the lithologic and SPT N values at each borehole. In the study area, the SPT test was terminated when the N value reached 50 which corresponds to the hard gravelly silt soil. The SPT test was only conducted in soft soil zone without penetrating the bedrock, whereas for the seismic survey, some of the 2D velocity model cross sections show P-wave velocity values range from 3500 to 4000m/s at a depth of more than 15m. This high velocity values can be interpreted as representing slightly weathered to fresh rock.

Introduction

Seismic refraction is a commonly used geophysical technique to determine and characterize the soils and rocks based on velocities (Sjogren et al., 1979). The refraction surveys can also provide data related to construction, such as rippability and earthwork factor (Redpath, 1973). Intercept-time and reciprocal methods of interpreting refraction data can be used to model velocity structures of the subsurface materials (Hagedoorn, 1959 and Palmer, 1981). Those methods are only applicable to sites where subsurface layers have uniform velocities and layers dip less than 20 degrees as it assumes a layered model and continuity of refractor surfaces across a profile. However the subsurface velocity can be complex especially in areas dominated by dipping metasedimentary rocks, making them difficult to accurately model using intercept-time and reciprocal methods. Lateral and vertical changes in velocity, steeply dipping and discontinuous refractors are commonly observed in refraction surveys (Jones and Jovanovich, 1985). Refraction tomography, another method of interpreting seismic refraction data, uses a gridded, inversion technique to determine the velocity of individual 2-D blocks within a profile as opposed to modeling velocities as layers (Pullammanappallil and Louie, 1994). Using first arrival picks, the software develops a best-fit velocity model by iteratively comparing different velocity distributions with observed data. This paperwork presents some of the inversion results carried out on several survey lines in the study area (Figure.1). The velocity models were also compared with the existing boreholes Standard Penetration Tests (N values) and lithological logging data.

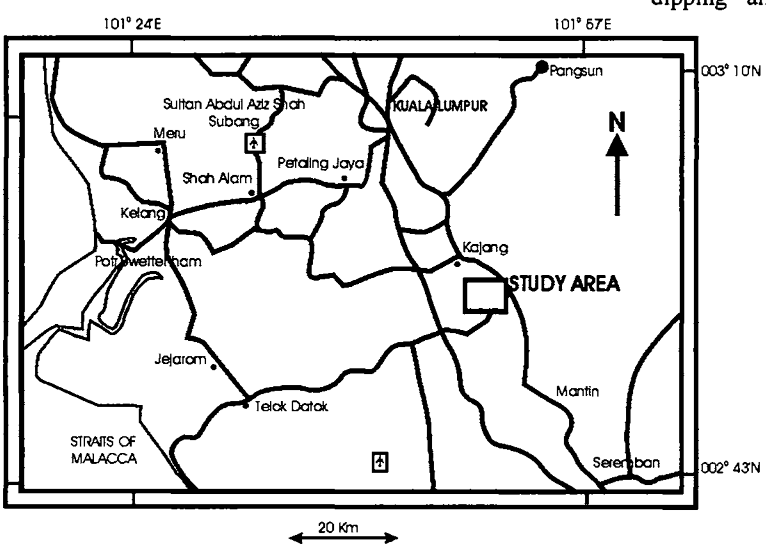


Figure 1: Location of survey area

Methodology

The survey area consists of interbedded shale, siltstone and sand stone

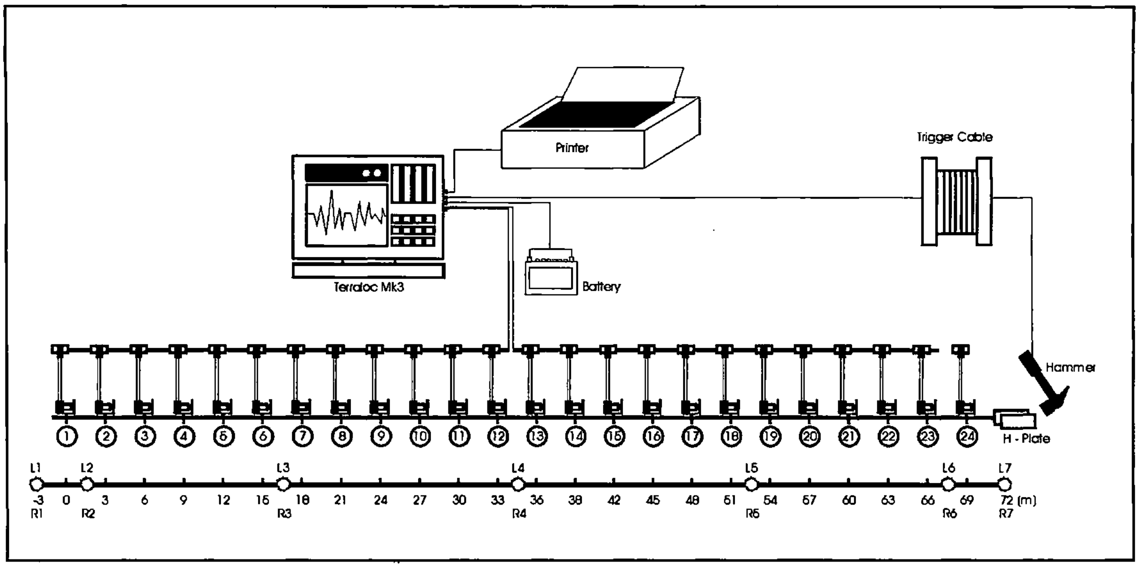


Figure 2: Positions of shots and geophones in the field data collection

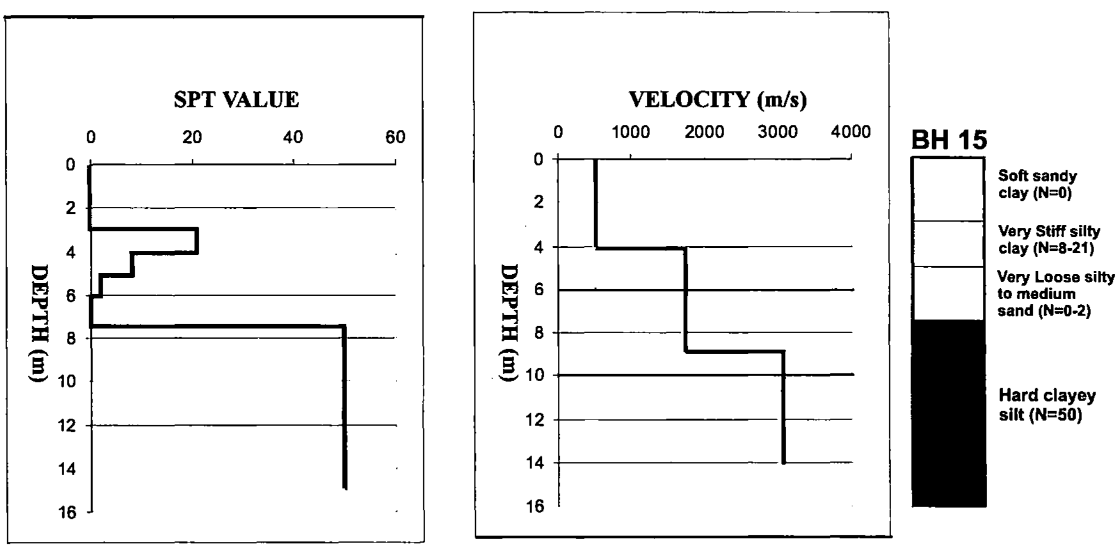
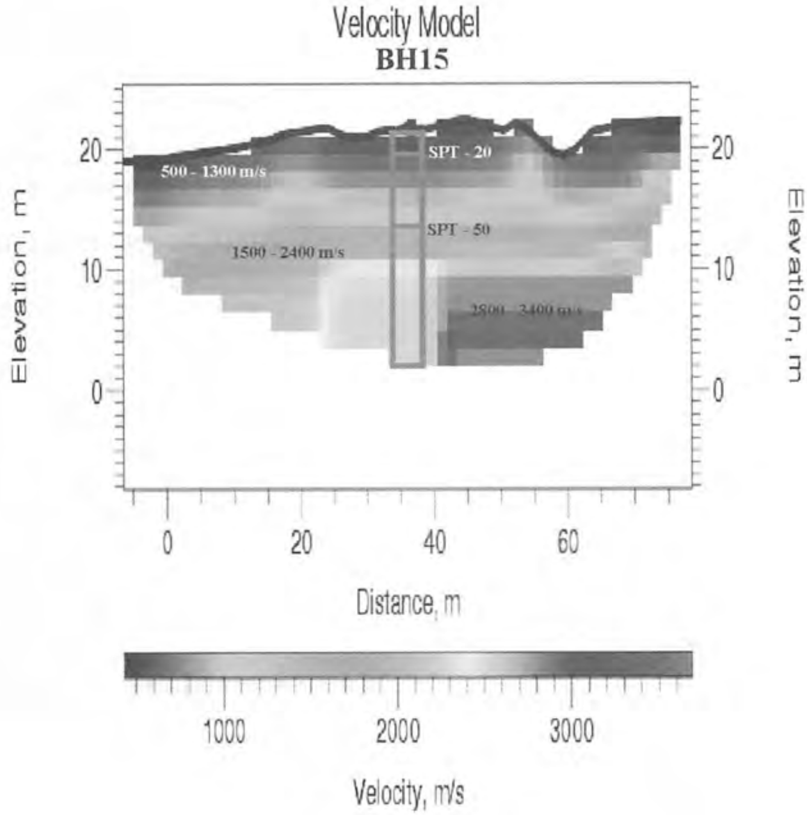


Figure 3: SPT values and 1-D velocity-depth curve for borehole 15



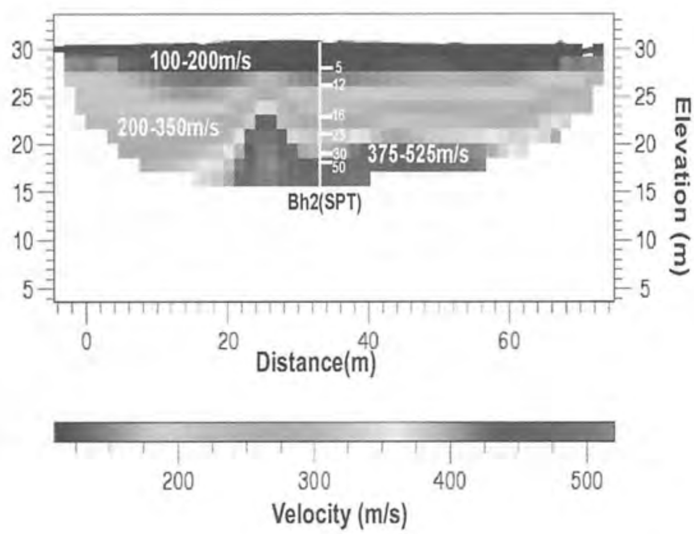


Figure 4 (top): P-wave velocity model of a survey line near borehole 15

Figure 5 (bottom): S-wave velocity model of a survey line near borehole 2

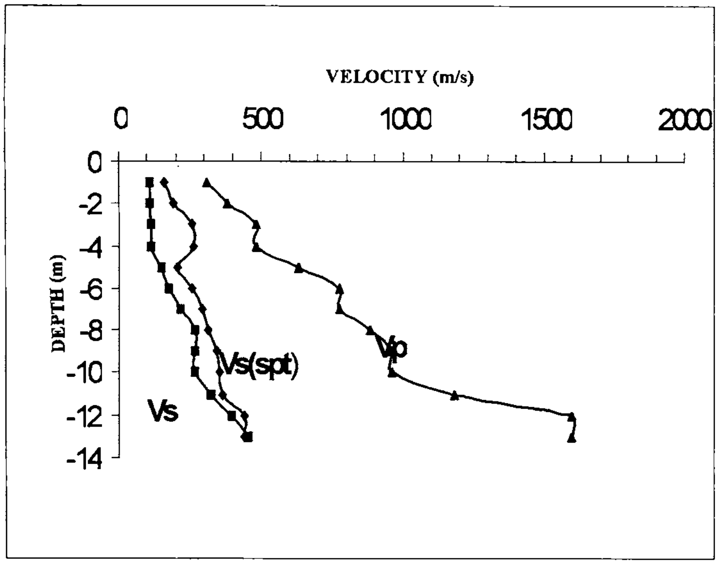


Figure 6: P-S waves curves versus depth

of Kenny Hill Formation. These metasediment rocks are of late Paleozoic in geological age and stratigraphically overlying the older Kuala Lumpur limestone. The Kenny Hill Formation was deposited in shallow marine environment and has been metamorphosed to a green schist and argillite facies (Hamzah, 1980). These metasedimentary rocks are not exposed in the study area since it is covered by a rather thick residual soil.

The P and S seismic survey have been carried out along severel lines across boreholes in the study area. Offset and geophone spacing used in this survey was 3 metres. A 5 kilogram sledgehammer and a square-shape steel plate were used to produce the seismic wave. P-wave is produced by hitting the steel plate vertically while the same hammer is hit on both side of a H-shaped steel plate to generate the S-wave. Figure 2 shows the source and geophone positions along the survey line used in this study. Three to five blows of vertical stacking are applied to produce the P-wave source and an even number of blows are applied to produce the S-wave source. ABEM MK3 seismograph was used throughout the survey for data recording and 24 low-frequency (14Hz) vertical and horizontal geophones were used for sensing the returned wave energy (Chun, 2003).

The P and S types first arrival data picked from the seismic record were used as input to produce inverse velocity model by OPTIM software developed by Pullammanappallil and Louie (1994). The resulting 2D velocity models were then compared with the borehole Standard penetration test (SPT) log in order to see the correlation between the velocity, SPT and depth.

SPT is a routine test in civil engineering work for estimating the density and stiffness of soil at any construction site. The test is concurrently done during the drilling and disturbed soil sampling at every 1.5m depth. In this site investigation borehole, a 51 mm split tube sampler is driven for 150 mm. using a 64 kilogram hammer dropped at 760 mm, number of blows (N) is counted to drive the tube the next 300 mm. Table 1 shows the approximate N values of very loose to very dense material

RESULTS AND DISCUSSION

Based on borehole 15 as shown in Figure. 3, materials in the study areas can be classified as clayey silt, sandy silt, and sandy silt with gravel. The figure also shows the SPT values of the borehole as well as velocity depth function from a seismic survey carried out near the borehole. The SPT value increases at the boundaries of soft sandy clay-very stiff silty clay and loose sand-hard clayey silt. Similar increase in seismic velocity is also observed but at depth one meter below these two boundaries. P-wave velocity increased from 500 m/s to about 1800 m/s at depth of 4 meter below the surface which is one meter below the soft sandy clay-stiff silty clay boundary. The velocity is also increased from 1800 m/s to about 3000 m/s at depth of 9 meter below the surface which is about one meter below the boundary of loose silty sand-hard clayey silt boundary.

Figure 4 shows a velocity model of a seismic line near borehole 15. The model shows velocity variation from as low as 500 m/s until 3700 m/s with a maximum depth of penetration at about 30m below the surface. These velocities represent various materials from soft clay to hard sandy silt of Kenny Hill Formations. By comparing the results of SPT and the velocity model, materials at depth of 0-3m and with velocity ranging from 500 to 1300 m/s are found to correspond to clayey silt with SPT index less than 20. The underlying materials at depth of 3-7m with velocity ranging from 1500 to 2400m/s correspond to silty material mixed with gravel. This material has the SPT value ranging from 20 to 50 which is physically considered as dense. The layer at depth of 7 to 17m with high velocity values ranging from 2500 to 3600 m/s and SPT N-values greater than 50 corresponds to hard clayey silt.

In this study, borehole-SPT index were also compared with S-wave velocity model. Figure 5 shows an example of superimposed SPT-velocity model for

Material	SPT value
Very loose	<5
loose	5-10
Moderately dense	11-30
dense	31-50
Very dense	>50

Table 1: SPT values for loose and dense materials

Depth (m)	SPT	Vp (m/s)	Vs (m/s)	Vs (SPT) m/s	Poisson Ratio
1	3	310	109	160	0.43
2	5	380	109	192	0.46
3	11	485	114	255	0.47
4	12	485	114	263	0.47
5	6	631	148	205	0.47
6	11	774	176	255	0.47
7	16	774	215	291	0.46
8	20	884	268	316	0.45
9	25	963	268	343	0.46
10	28	962	265	357	0.46
11	30	1184	326	366	0.46
12	50	1598	395	440	0.47
13	50	1598	457	440	0.45

Table 2 SPT, P-S waves and Poisson ratios for borehole 2

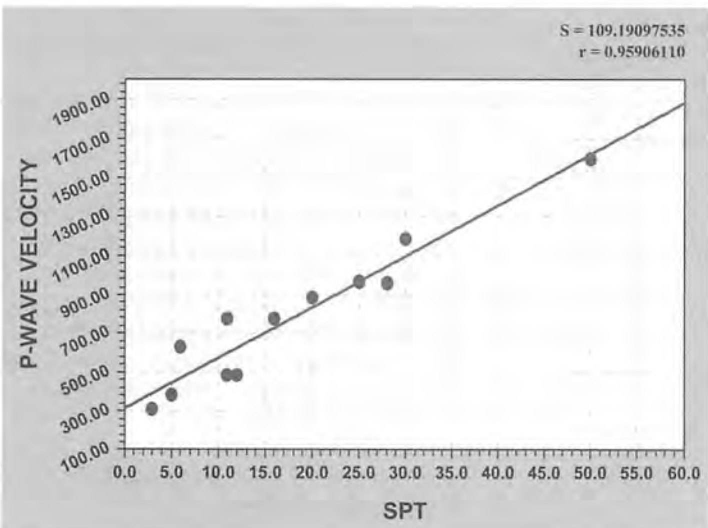


Figure 7: P-wave versus SPT plot

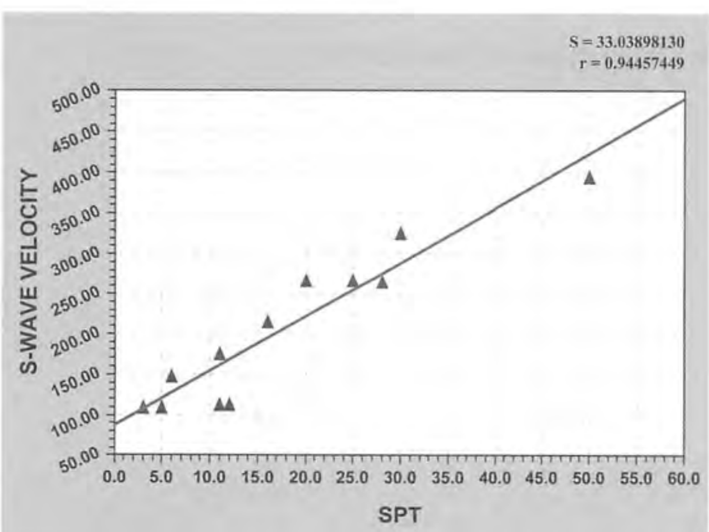


Figure 8: S-wave versus SPT plot

borehole 2. This section shows that the velocity at depth ranges from 100 to 525 m/s which are typical values of weathered materials. Close to the surface, the velocity model shows a thin layer of about 3m with a seismic S-velocity below 200 m/s and SPT N-value ranging from 5 to12. This seismic layer corresponds to a soft clayey silt. The softness of the weathered layer progressively decreases with depth as is shown by the increase of seismic S-wave velocity from 200 m/s at about 4m depth to about 350 m/s at 7 to 14 m depth. This layer corresponds to sandy silt with gravel and has SPT N-values ranging between 12 to 25. The hardest layer is located at the bottom of this velocity model with material corresponds to hard sandy silt of S-wave velocity ranging from 375 m/s to 525 m/s and SPT N-values ranging from 30 to 50.

P-S wave velocities from surface to the deepest part of the velocity model at an interval of 1m have been determined and plotted against the SPT data. Poisson ratios were also calculated from these P-S velocities. S-wave velocities derived from SPT N-values plus P-S velocities and SPT index data were plotted for each borehole for camparison. An example of this plot for borehole 2 is shown in Figure 6 and all data are listed in Table 2. S-wave velocities from seismic survey and calculated from SPT show only slight difference. The Poisson ratio values which are ranging from 0.43 to 0.47 correspond to soil. In this study, SPT N=50 represents dense weathered soil which is located above the fresh bedrock. Figure 7 shows the curve of P-wave velocity plotted against SPT values. This curve shows a linear trend between P-velocities and SPT N-values. P-wave velocity at SPT N=0 is 300 m/s. Fig. 8 shows the curve of S-wave velocities plotted against SPT. The curve also shows similar positive trend of increasing velocity with increasing SPT values. For this curve, S-wave velocity estimated at SPT N=0 is about 85 m/s. These correlations can be very useful in site investigation in the absence of drilling data.

CONCLUSION

2D seismic refraction tomography is one of the efficient tools to investigate the strength of subsurface soil and rock masses along a survey line. Soil strength informations obtained from SPT N-values will only represent rock mass in a particular borehole. Integration of seismic refraction tomography and SPT can be used to investigate the vertical and horizontal variation of velocities. In the absence of SPT data, the velocity model can be used to estimate the strength of a rock mass based on the established velocity-SPT N-values correlation.

REFERENCES

Chun, Y.C. 2003. Pencirian seismos di tapak cadangan pembinaan MINT, Dengkil Tesis SmSn UKM (unpublished).

Hagedoorn, J.G. 1959. The plus-minus method of interpreting seismic refraction sections. Geophysical Prospecting 7:158-182.

Hamzah, M. 1980. Geologi kawasan Salak-Labu, Selangor-Negeri Sembilan. Tesis SmSn UKM (unpublished).

Jones, G.M., and Jovanovich, D.B.1985. A ray inversion method for refraction analysis.Geophysics 50:1701-1720.

Palmer, D. 1980. The generalized reciprocal method of seismic refraction interpretation. Society of Exploration Geophysicists, Tulsa, OK, 104p.

Pullammanappallil, S.T., and Louie, J.N. 1994. A generalized simulated-annealingOptimization for inversion of first-arrival times. Bull. of the Seismological Society of America 84(5): 1397-1409

Redpath, B.B. 1973. Seismic refraction exploration for engineering site investigation,U.S. Army Engineer Waterways experiment station explosive excavation research laboratory, technical report E-73-4, Livemore, California, 51p.

Sjorgen, B., Ofsthus, A., and Sandberg, J. 1979. Seismic classification of rock mass qualities. Geophysical Prospecting 27:409-442.

Manuscript received 9 March 2006