ARPN Journal of Engineering and Applied Sciences

SOIL INVESTIGATION USING MULTICHANNEL ANALYSIS OF SURFACE WAVE (MASW) AND BOREHOLE

Aziman Madun[1,2], Muhammad Ersyad Ahmad Supa'at[1], Saiful Azhar Ahmad Tajudin[1,2], Mohd Hazreek Zainalabidin[1,2], Salina Sani[1,2] and Mohd Fairus Yusof[1,2]
[1]Department of Infrastructure and Geomatic, Universiti Tun Hussein Onn Malaysia
[2]Research Centre for Soft Soil, Universiti Tun Hussein Onn Malaysia
E-Mail: aziman@uthm.edu.my

ABSTRACT

Multichannel Analysis Surface Wave (MASW) measurement is one of geophysics exploration techniques to determine the soil profile based on velocity. Meanwhile borehole intrusive technique identifies the changes of soil layer based on SPT N value. Both techniques were applied at the University campus test site and Parit Jelutong as part of soil investigation. A 7 kg of sledge hammer was used as source, 24 units of 4.5 Hz geophones used as detectors (receivers) and Terraloc Mark 8 ABEM was used as a recorder. SeisImager software was used for seismic data processing. The MASW test configuration was 5 m geophones spacing and 5 m source offset distance at Parit Jelutong, and used 1 m geophones spacing and 2 m offset distance at the University campus test site. All the MASW test array was conducted near to the boreholes. The reliable seismic results at Parit Jelutong were from depth 0.5 m to 14 m and 3.7 m to 27 m the University campus test site, respectively. Comparison between MASW and borehole data indicates that a very soft clay shear wave velocity is below than 165 m/s, soft clay at 170 m/s to 195 m/s and firm layer at 194 m/s to 317 m/s. There was not available shear wave velocity result of hard material. In conclusion, the MASW technique is potential to adapt in soil investigation to compliment the intrusive technique, which is non-destructive, non-invasive nature and relative speed of assessment.

Keywords: multichannel analysis of surface wave, site investigation, shear wave.

INTRODUCTION

In situ field testing enables larger volumes of soil to be tested and so tends to be more representative of the soil mass compared with laboratory testing. In situ field tests have an advantage as samples do not need to be retrieved. For very soft clays, sands and gravels, sampling is a major problem because these materials easily change their soil structure and, as a result, produce disturbed samples. Good correlations have been produced between field tests and laboratory tests, which has led to acceptance of field techniques (Charles and Watt, 2002). Of the range of in situ tests, penetration testing, dynamic probing, pressuremeter testing, field vane shear testing, plate loading testing and geophysical testing are used for site investigations. Cost and time constraint factors are the main reasons why it is not easy to investigate the subsurface completely. Hence, site investigation may only involve the laboratory testing of samples collected by site personnel or field testing for limited areas. This may lead to either an underestimate or overestimate of the strength of the existing subsurface. Therefore, to achieve greater certainty of the site investigation, a robust approach is needed to adopt. Geophysical methods can provide excellent resolution of spatial variability across a site. The main advantages with such an approach are their non-destructive, non-invasive nature and relative speed of assessment. If calibrated, details of stiffness with depth can be relatively easily obtained.

The choice of which geophysics tests to use depends on the parameters to be examined. However, obtaining the soil stiffness profile is particularly important in the site investigation (Mitchell and Jardine, 2002). Amongst geophysical methods, the seismic method based results are empirically derived Geotechnical properties such as maximum shear modulus, bulk modulus (B), Young's modulus (E), and Poisson's ratio (Charles and Watts, 2002; Crice, 2005). The seismic-based techniques have proved particularly useful in determining the shear modulus profile from site investigation (Moxhay *et al*., 2001; Siti Zuraidah *et al*., 2015). There are two methods of obtaining seismic wave data that can potentially be used for site investigation (1) borehole methods and (2) surface methods (Menzies, 2001). The surface wave data collection uses the surface method, which is more versatile than other methods because it is not constrained by any ground models and considered more economical in terms of field operation (Matthews *et al*., 2000).

The Multi-channel Surface Wave (MSW) method originated 50 years ago in Japan and was called the micro-tremor survey method (MSM). In the late 1990s, electronic equipment for the MSW was developed by the Kansas Geological Survey called multi-channel analysis of surface wave, MASW (Park *et al*., 1999). This technique has been developed and tested for applications in civil engineering, for example, for site characterisation (Long and Donohue, 2007) and for compaction control by measuring the decay of soil vibrations (Adam *et al.*, 2007) and quality of stone column (Madun *et al*., 2012). The approach of the MSW offers considerable advantages over conventional surface wave analysis techniques that are

 ISSN 1819-6608

ARPN Journal of Engineering and Applied Sciences

based upon a single transmitter-receiver pair. The method of carrying out measurements using a multiple-receiver strategy reduces survey time and allows lateral resolution to be obtained (Zywicki, 1999; Park *et al*., 1999), while the sub-surface characterisation in both the vertical and lateral axes provide a useful 2-D representation (Socco and Strobbia, 2004). MASW introduced by Park *et al.* (1999) uses many receivers, with only one shot, from which it is capable of identifying, isolating and removing noise from scattered and reflected waves during the data analysis. As a result, a best fit line can be drawn through the phase angle-distance plot, thus minimizing the influence of variations in data and allowing enhanced robustness in data processing. The entire procedure for MASW usually consists of three steps: firstly is acquiring multi-channel field records, secondly extracting dispersion curves and finally, inverting these dispersion curves to obtain 1-D or 2-D shear wave velocity and depth profiles. The MASW method has improved production in the field and improved characterisation of dispersion relationships by sampling the spatial wave field with multiple receivers (Park *et al.,* 2007).

In general, the Multi-channel of Surface Wave (MASW) method has significant advantages over other surface wave techniques as all seismic wave energy, consisting of both body and surface waves, is recorded by multi-channel receivers. Seismic waves propagate in the form of body waves and surface waves. The difference between the two is that body waves are usually non-dispersive. In a solid and homogeneous medium, the velocity of surface waves does not fluctuate significantly as a function of distance propagated. However, when the properties of the medium vary with depth, surface waves become dispersive such that the velocity of propagation varies with respect to wavelength or frequency. Multi-channel of Surface Wave (MASW) method has investigation depth shallower than 30 m and whereas the passive method (source like traffic and tidal motion) can reach a few hundred meters. Sampling redundancy due to multi receivers provides flexibility in the signal processing approach to extract the dispersion curve. Many advantages had been stated above, and thus, the evaluation of this technique for site investigations apply on soft soil is conducted to make stakeholders aware this technique. This study aim to investigate the soil profile based on MASW technique and calibrated with borehole data on marine clay deposit at Parit Raja, Johor. The location of this study is shown in Figure-1, on campus of Universiti Tun Hussein Onn Malaysia and Parit Jelutong. This location consists of marine clay and silt deposits at Quaternary aged.

Figure-1. Test locations at university campus and Parit Jelutong.

METHODOLOGY

Multi-channel of Surface Wave (MASW) method used similar equipment in seismic refraction method, but different geophones frequency. A 7 kg of sledgehammer is used as source that impacted to the metal plate. A 24 unit of 4.5 Hz vertical geophone is used as detector which connects with 24 channel cable and ABEM Terraloc MK-8 seismograph was used for recorder. Figure 2 shows an arrangement of the shot point location and geophones for Multi-Channel Analysis of Surface Wave (MASW) test.

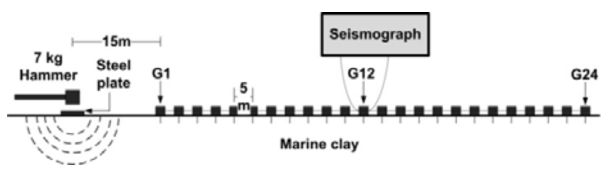

Figure-2. Equipments arrangement for multi-channel analysis of surface wave (MASW) test.

The seismograph setting for MASW test required longer record time, i.e. about 2 second requires to measure seismic data. The sampling interval between 250 and 500 µs and number of samples 4096 and 8192. Hammering the ground about 5 times to produce active waves. The length of array and distance seismic source to first geophone at Parit Jelutong and the university campus test site at 115 m and 5 m; and 23 m and 2 m, respectively. MASW tests were conducted closed at the borehole location.

RESULTS AND DISCUSSIONS

Shear wave velocity profiles at Parit Jelutong and the university campus test site were analyzed by using SeisImager software to produce 1-dimensional velocity profile. MASW tests conducted at Parit Jelutong indicated the information up to 27 m depth, meanwhile at the university campus test site at 13 m as shown in Figure-3. The depth of penetration is controlled by the length of MASW array used in the study. At Parit Jelutong and the

ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

university campus test site have three boreholes. From borehole data, the soil layers were divided into very soft, soft, firm and hard clay layer. Tables 1 and 2 tabulated the summaries of the borehole and MASW results at Parit Jelutong Spreadline 1 and 2. While Table-3 shows the result at the university campus test site. At deeper layer, the shear wave velocity data not available due to the limitation of MASW test. The result shows that the subsurface can be categorized into very soft soil for SPT N below than 2 and the shear wave velocity below than 165 m/s. Meanwhile the soft soil layer indicates by the SPT N between 2 and 4 has shear wave velocity between 170 m/s and 191 m/s. Finally, the firm soil layer at SPT N between 4 and 8 has shear wave velocity between 194 m/s and 317 m/s.

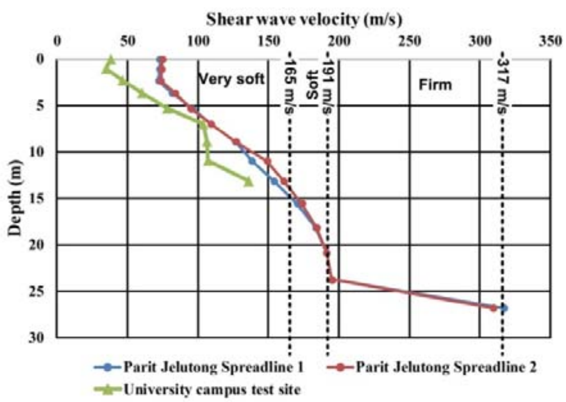

Figure-3. MASW tests result of two spreadline at Parit Jelutong and one spreadline at university campus test site.

Table-1. Parit Jelutong borehole 1 and spreadline 1.

Depth (m)	Soil Description	SPT N Value	Shear wave velocity, m/s
0.0 - 15.0	Very soft	0-2	71 - 154
15.0 - 24.0	Soft	2-4	170 - 191
24.0 - 30.0	Firm	4-8	194 - 317
30.0 - Above	Hard	>30	Not available

Table-2. Parit Jelutong borehole 2 and spreadline 2.

Depth (m)	Soil Description	SPT N Value	Shear wave velocity, m/s
0.0 - 15.0	Very soft	0-2	73 - 161
15.0 - 27.0	Soft	2-4	173 - 191
27.0 - 30.0	Firm	4-8	195 - 309
30.0 - Above	Hard	>30	Not available

Table-3. University campus test site borehole 1 and spreadline 1.

Depth (m)	Soil Description	SPT N Value	Shear wave velocity, m/s
0.0 - 15.0	Very soft	0-2	38 - 165
15.0 - 27.0	Soft	2-4	Not available
27.0 - 30.0	Firm	4-8	Not available
30.0 - Above	Hard	>30	Not available

The SPT N value from borehole data was used to estimate shear wave velocity via empirical conversion of $Vs = 105.70N^{0.327}$, that suitable for all types of soils (Tsiambaos G. and Sabatakakis N., 2011). Figure-4 shows the shear wave velocities measured using MASW and empirical conversion for data at Parit Jelutong. The shear wave velocities calculated using an empirical formula has good agreement with measured shear wave velocity using MASW technique. However, the empirical conversion of the shear wave velocities showed a small fluctuation compared with the measured velocity using MASW. It's due to the MASW data measured larger area and averaged the velocity across the area, meanwhile the borehole SPT N value is specifically at a certain depth. It is worth noting that the geophones spacing was 5 cm and length of an array was 115 m at Parit Jelutong. The MASW results produced a profile of the average of shear-wave velocity versus depth in the surrounding soil. In addition, the theory of inversion techniques in MASW deal with the assumption that the soil in layered with vertical heterogeneity and lateral homogeneity.

ARPN Journal of Engineering and Applied Sciences

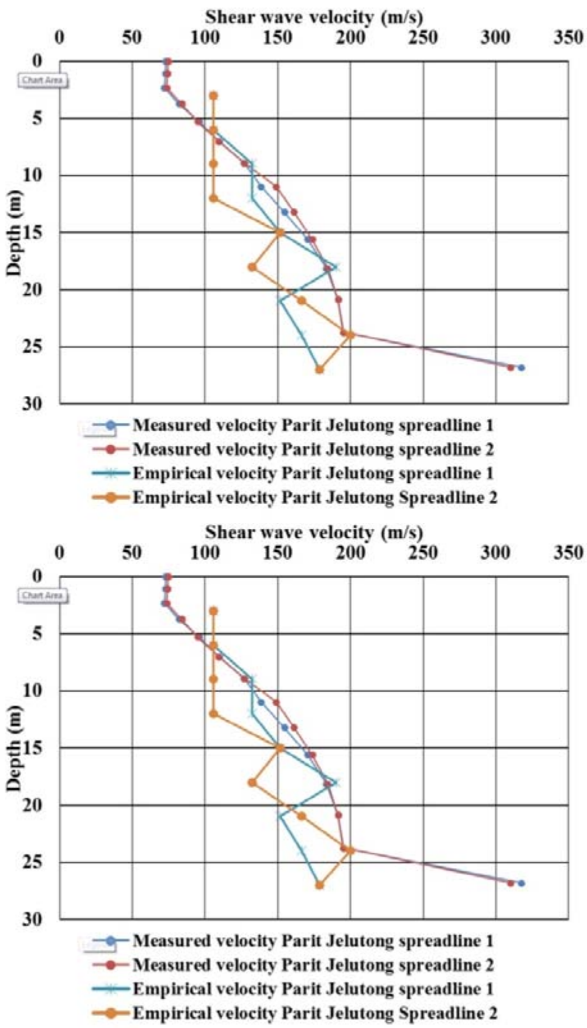

Figure-4. The shear wave velocities measured using MASW and empirical conversion SPT N data at Parit Jelutong.

CONCLUSIONS

The shear wave velocities can divided into three layers of soils based on SPT N values, i.e. velocity below than 165 m/s, between 165 and 191, and 191 m/s to 317 m/s were classified as very soft, soft and firm soil, respectively. The shear wave velocity obtained using MASW technique is representing the average of the velocity at specified depth across the lateral length of the array. Thus, it is expected that the velocity from empirical conversion using the SPT N value slightly deviated as compared with MASW test due to the variability of soil horizontally. Therefore the soil profile correlation between MASW test and borehole SPT N value must be understood its limitation. In conclusion, the MASW technique is potential to adapt in soil investigation to compliment the intrusive technique, which is non-destructive, non-invasive nature and relative speed of assessment.

ACKNOWLEDGEMENTS

The authors would like to thank the University of Tun Hussein Onn, Malaysia, and the Ministry of Higher Education, Malaysia, FRGS vot. 1455 for their generous sponsorship of this research.

REFERENCES

Adam, D., Brandl, H. and Kopf, F. et al. 2007. Heavy tamping integrated dynamic compaction control. Ground Improvement, 11 (4): pp. 237–243.

Charles, J.A. and Watts, K.S. 2002. Treated ground engineering properties and performance. London: Construction Industry Research and Information Association, ClRlA C572.

Crice, D. 2005. MASW: the wave of the future. Journal of Environmental and Engineering Geophysics, 10(2): pp. 77-79.

Madun, A., Jefferson, I., Foo K.Y., Chapman, D.N., Culshaw, M.G. and Atkins, P.R. 2012. Characterization and quality control of stone columns using surface waves testing. Canadian Geotechnical Journal, Vol. 49, No. 12, pp. 1357-1368.

Matthews, M.C., Clayton, C.R.I. and Own, Y. 2000. The use of field geophysical techniques to determine geotechnical stiffness parameters. Proceedings of the Institution of Civil Engineers Geotechnical Engineering, 143: pp. 31-42.

Menzies B.K. 2001. Near-surface site characterisation by ground stiffness profiling using surface wave geophysics." In Instrumentation in Geotechnical Engineering (eds K.R. Saxena and V.M. Sharma), H.C.Verma Commemorative Volume, 43-71. Oxford and IBH Publishing Co. Pvt. Ltd., New Delhi, Calcultta.

Long, M. and Donohue, S. 2007. In situ shear wave velocity from multichannel analysis of surface waves (MASW) tests at eight Norwegian research sites. Canadian Geotechnical Journal, 44: pp. 533-544.

Mitchell, J.M. and Jardine, F.M. 2002. A guide to ground treatment. London: Construction Industry Research and Information Association, ClRlA C573.

Moxhay, A.L., Tinsley, R.D. and Sutton J.A. 2001. Monitoring of soil stiffness during ground improvement using seismic surface waves. Ground Engineering Magazine, January: pp. 34-37.

ARPN Journal of Engineering and Applied Sciences

Park, C.B., Miller, R.D., and Xia, J. 1999. Multichannel analysis of surface waves. Geophysics, 64(3): pp. 800-808.

Park, C.B., Miller, R.D. and Xia, J. 2007. Multichannel Analysis Of Surface Waves (MASW)-Active And Passive Methods. The Leading Edge, January 2007, pp. 60-64.

Siti Zuraidah Z., Aziman M., Ariffuddin J. and Mohammad Faiz L.A. (2015). Seismic Surface Wave Testing for Investigating the Shallow Soil Profile. Applied Mechanics and Materials Vols 773-774, pp 1565-1568.

Socco, L.V. and Strobbia, C. 2004. Surface wave method for near-surface characterization: a tutorial. Near Surface Geophysics, 2004, pp. 165-185.

Tsiambaos G. and Sabatakakis N. 2011. Empirical estimation of shear wave velocity from in situ test on soil formation in Greece. Bulletin of Engineering Geology and Environment, 70: pp. 291-297.

Zywicki, D.J. 1999. Advanced signal processing methods applied to engineering analysis of seismic surface waves. PhD thesis, Georgia Institute of Technology.