

Characterisation of Lateral and Vertical Subsurface Heterogeneity in the Ground using Sustainable Seismic Surface Wave Methodology

Madun, A.*, Wijeyesekera, D. C., Ahmad Tajuddin, S. A., Zainalabidin, M. H., Yunus, R. and Tajul Baharudin, M. F.

Faculty of Civil and Environmental Engineering & Research Centre for Soft Soil, University of Tun Hussein Onn, 84600 Parit Raja, Johor, Malaysia

ABSTRACT

Seismic surface waves are a non-destructive technique used to obtain the dynamic properties of soil by measuring the shear wave velocity and calculating the shear modulus of soil. The shear modulus is one of the parameters to measure the stiffness of materials. This study evaluates soil profiles and the position of the sensor while conducting measurements of two soil profiles, i.e. lateral and vertical non-homogeneities, using a continuous surface wave analysis (CSW) and multi-channel analysis of surface waves (MASW). Results showed the dispersive curve demonstrated an increased shear wave velocity with increasing depth for the sensor pair measurements on the clay (between columns), and decreased shear wave velocity with increasing depth for the sensor pair measurements on the column. In both instances the surface wave velocity results influenced by the depth and size of the wavelength, indicating that depth and wavelength controlled the volume of measurement in an elliptical shape. Therefore, the shear wave velocities and thus stiffness measured from the surface wave velocity techniques are represented the volume of soil measured across the sensor length.

Keywords: Continuous surface wave analysis, multi-channel analysis of surface wave, seismic surface wave testing, site investigation

ARTICLE INFO

Article history:

Received: 29 September 2016

Accepted: 05 April 2017

E-mail addresses:

aziman@uthm.edu.my (Madun, A.),

devapriya@uthm.edu.my (Wijeyesekera, D. C.),

saifulaz@uthm.edu.my (Ahmad Tajuddin, S. A.),

hazreek@uthm.edu.my (Zainalabidin, M. H.),

riduan@uthm.edu.my (Yunus, R.),

mdfaizal@uthm.edu.my (Tajul Baharudin, M. F.)

*Corresponding Author

INTRODUCTION

One of the main parameters used for predicting ground movement is its stiffness profile (Abbiss, 1981; Matthews et al., 1996). Stiffness can be defined as the resistance of the body to deformation under applied force (Clayton, 2011). The seismic-based techniques shake the ground and produces

very small strains and soil velocities measured to derive the geotechnical properties related to strain, maximum shear modulus, bulk modulus (B), Young's modulus (E), and Poisson's ratio (ν) (Badee et al., 2016; McDowell et al., 2002; Crice, 2005). Stiffness can be measured using seismic surface wave techniques such as continuous surface wave analysis (CSW) and multi-channel analysis of surface waves (MASW). Many studies had been conducted to obtain an empirical correlation between seismic data and geotechnical parameters. However, due to the heterogeneities of the ground the empirical correlation between seismic and geotechnical parameter is unique (Madun et al., 2010a; Madun et al., 2016c; Madun et al., 2016d). As experience by Ahmed et al. (2012) were made mistake in its interpretation of the shallow bedrock instead of a very soft sediment due to subsurface condition when using the multi-channel analysis of surface wave (MASW) technique. In contrast Matthews et al. (1995) concluded seismic wave technique can deliver results of significant quality and avoid the disadvantages associated with either laboratory or physical field tests. Therefore to ascertain seismic profile the nature of the ground has to be studied. In this paper soil profiles and the position of the sensor is evaluated when conducting seismic wave measurement. Two soil profiles, i.e. lateral and vertical non-homogeneities were evaluated using a continuous surface wave analysis (CSW) and multi-channel analysis of surface waves (MASW), respectively. The continuous surface wave analysis (CSW) used a pair of sensor while multi-channel analysis of surface waves (MASW) used 24 sensors. The aim of this paper was to evaluate the seismic surface wave test for characterizing the lateral and vertical non-homogeneities. Results of lateral non-homogeneities measurements are based on previous published papers (Madun et al., 2012b). Meanwhile, vertical heterogeneity was evaluated on soft marine clay deposits at the university campus. The site profile was confirmed via borehole records (Azhar et al., 2016; Madun et al., 2012e; Noor et al., 2016).

MATERIALS AND METHODS

Two cases soil profiles, i.e. lateral and vertical non-homogeneities were evaluated using a continuous surface wave analysis (CSW) and multi-channel analysis of surface waves (MASW), respectively. Lateral non-homogeneities measurements conducted in laboratory-scale stone column model using continuous surface wave analysis (CSW) method was explained in Madun et al. (2012a). The array of receivers consisted of up to four piezoelectric accelerometers. The shaker as a seismic source was located at the middle of sensor-pairs. This technique is called the continuous surface wave analysis (CSW). The distance between the source and the first receiver, d , was set at 7 cm and receiver spacing, Δx , was 3 cm. The equipment was set up on the soft clay that contained the gravelly sand columns. The measurements made were: sensor-pair on column and sensor-pair between columns.

Vertical non-homogeneities measurements were conducted at a test site in the campus of Universiti Tun Hussein Onn Malaysia using the multi-channel analysis of surface waves (MASW) method. The borehole was located at the centre of the multi-channel analysis of surface waves (MASW) array. The MASW method uses an active seismic source which means the seismic wave energy generated at specified location along linear direction with spread length. This method requires three components, i.e. seismic source, sensor and data logger. A 7

kg of sledgehammer was used as source that impacted to the metal plate. The distance between source to the first sensor at set up at 15 m and sensor spacing of 5 m. The 24 sensors of 4.5 Hz vertical geophones were used to connect with 24 channel cables and ABEM Terraloc MK-8 seismograph was used as data logger. The record data at least 1 second length with sampling interval and number of samples at 250 μ s and 4096 respectively. Any filtering of noise must be turned off, in order to capture any seismic wave data. Array line cable at a length of 115 m long and should be in linear. The MASW data was processed using SeisImager software by Geometric.

RESULTS AND DISCUSSION

Seismic Surface Wave Test Results

Lateral Heterogeneities Laboratory Experimental. Figure 1 shows the dispersion curves that was measured using sensors located on the clay region between columns and with sensors located on the 4-cm column. The shear wave velocities for sensors on clay was 62 m/s and then increased with larger wavelengths to 69 m/s. Meanwhile, the shear wave velocities measured on the column was 110 m/s decreased with increasing wavelengths to 67 m/s. Both dispersive curves demonstrate the influence of the lateral heterogenous introduced by the column within the soft clay.

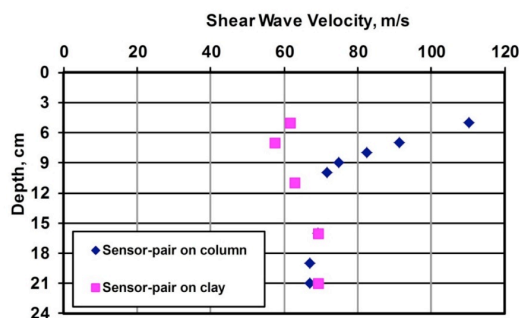


Figure 1. The shear wave velocities sharply decreased between depths 3.5 cm and 10 cm for sensor-pair on column

Vertical Heterogeneities Field Experimental. The MASW test result was performed with 24 sensors located on the soft clay region as shown in Figure 2. Figure 2(a) shows the dispersive curve of phase velocity versus frequency, and Figure 2(b) shows the shear wave velocity soil profile from MASW test and relate with the SPT-N value from borehole data. The shear wave velocities in clay were increased with increasing of the depth. For very soft clay shear wave velocity less than 103 m/s, soft clay velocity between 103 m/s and 210 m/s and firm clay velocity higher than 210 m/s. The shear wave velocities demonstrate the influence of the vertical heterogeneous which the SPT-N value increased by depth.

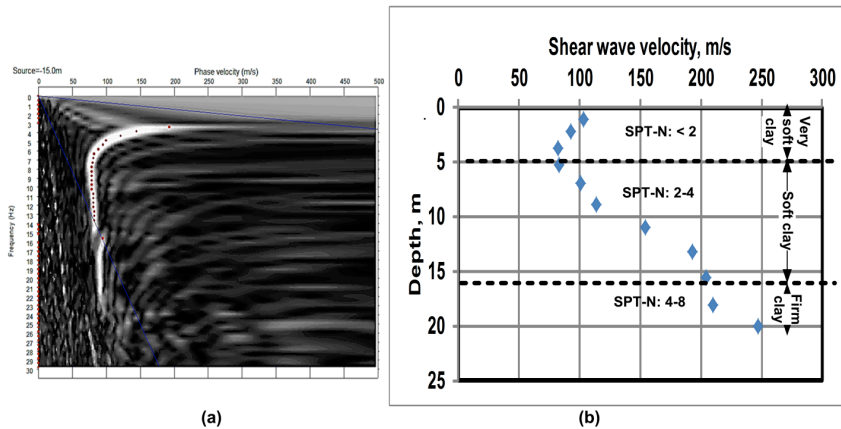


Figure 2. (a) Dispersion curve of MASW data; and (b) shear wave velocity profile after inversion from dispersive curve

DISCUSSION

The first case of lateral heterogeneity tested in the laboratory shows the characteristics of the dispersive curves of soft clay between 2 columns and another sensor pair on top of the 4 cm diameter column. The elliptical particle motion illustrated in Figure 3 explaining the downward trend in shear wave velocities for sensors on top of the column and upward trend for sensors on clay corresponding to depths and wavelengths. The growth of this effective region of measurement was presented the largest change in the averaged shear wave velocity. The illustrated elliptical region of measurement begins to encroach into the surrounding clay or column, but as it grows further, the change in ratio of column-to-clay. This illustration can explain the upward and downward trend in shear wave velocities for a sensor on clay and column with further increase in depth.

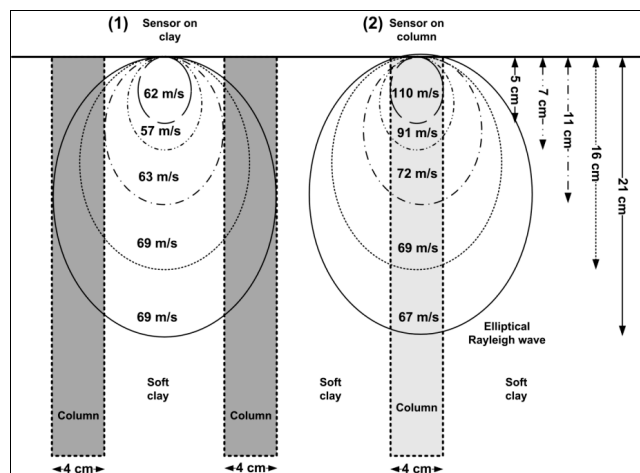


Figure 3. The shear wave velocities affected by the vertical and horizontal span of elliptical which encroach into the clay and column

In case of vertical heterogeneous, the relationship between the shear wave velocity and the effective region and wavelength is important for analysing and interpreting the measured result. As shown in Figure 4, almost 100 % of the elliptical effective regions sit within the first layer of very soft clay at a depth of 5 m. The wavelength will increase and the effective region will present the largest change in averaged shear wave velocity at the point where the elliptical begins to encroach into the second and third layer of soft and firm clay. This can explain the relationship between the upward trend in shear wave velocities and depth.

The test conducted in the laboratory and in the field, demonstrates that there is a relationship between shear wave velocity and the lateral, vertical, span of the effective measurement region. The shape and size of the effective region of measurement in the medium in the lateral and vertical dimensions can be used to identify the sampling volume of the wavelength. To date, this observation has received little attention in the literature on surface waves. The measured shear wave velocities via surface wave technique was shown to be influenced by the volume of measurement of Rayleigh wave with an elliptical particle movement, which in turn is a function of its wavelength. As a result, the measured shear wave velocities are directly influenced by the material as a medium for the energy transferred in the elliptical particle motion. This is important as it suggests that the wavelength not only relates to an effective depth, but may also have a lateral and vertical span and, therefore, is associated with an effective volume.

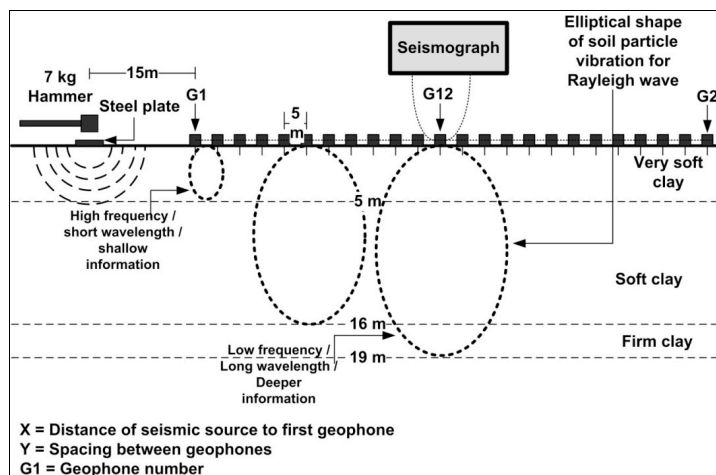


Figure 4. Sketch of the elliptical shape of phase velocities encroaching the surrounding clay

This laboratory and field study indicates phase velocity is influenced by both the vertical and horizontal spans of the material. Figure 3 and 4 shows the volume of each material in the effective region can be assessed by fitting the elliptical volume as a function of wavelengths. In real-world the relationship between the wavelength and the effective region of measurement (the sampling volume) is important when plotting a graphical representation of the dispersion curve and explain the variation and description of the soil boundaries. Consequently, the seismic

surface wave potentially can deliver a great device to evaluate the shear wave velocity in a non-destructive and non-invasive. It is important to understand that the MASW underestimates actual velocity for deeper layer if velocity increases with depth due to the effect of soil properties on the upper layer.

The velocity very soft clay is in the range of 57 m/s to 63 m/s and 83 m/s to 103 m/s when measured in the laboratory and field respectively. In the field, the effective stress controlled by the depth and groundwater level as well as confining pressure affects the pore water pressure, and can influence the shear wave velocity. The laboratory derived measurements served as a bench scale model, which does not involve any confining pressure and groundwater flow.

CONCLUSION

The surface wave testing to evaluate the factor of soil profiles and the position of the sensor were demonstrated in this study. Two soil profiles, i.e. lateral and vertical non-homogeneities, were evaluated using the continuous surface wave analysis (CSW) and multi-channel analysis of surface waves (MASW). Remoulded clay and gravelly sand columns from a typical stone column site create the lateral heterogeneous condition. The field test on soft clay was conducted at a test site which had the necessary soil profile. The study shows the shear wave velocity acquired from surface wave technique is dependent on the depth and the horizontal spans of the soil properties. Thus, the depth and horizontal spans could be adopted to identify the effective sampling volume. This allowed the dispersive curve to be projected and to evaluate the correlation between seismic velocity and soil index properties or soil strength.

ACKNOWLEDGEMENTS

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

REFERENCES

- Abbiss, C. P. (1981). Shear wave measurements of the elasticity of the ground. *Géotechnique*, 31(1), 91-104.
- Azhar, A. T. S., Hazreek, Z. A. M., Aziman, M., Haimi, D. S., & Hafiz, Z. M. (2016). Acidic barren slope profiling using electrical resistivity imaging (ERI) at Ayer Hitam area Johor. *Journal of Physics: Conference Series*, 710 (1) 012008, IOP Publishing.
- Badee, A., Ismail, B., Aziman, M, Lokmane, A., & Haimi, D. S. (2016). Effect of coarse materials percentage in the shear strength. *IOP Conference Series: Materials Science and Engineering*, 136 (1), 012017, IOP Publishing.
- Ahmed, I., Edward, S., Andrew, P., & Andrew, S. (2012). Pitfalls in interpretation of shallow seismic data. *Applied Geophysics*, 9(1), 87-94.
- Clayton, C. R. I. (2011). Stiffness at small strain: research and practice. *Géotechnique*, 61(1), 5-37.

- Crice, D. (2005). MASW: the wave of the future. *Journal of Environmental and Engineering Geophysics*, 10(2) 77–79.
- Luna, R., & Jadi, H. (2000). Determination of dynamic soil properties using geophysical methods. *Proc. of the First International Conference on the Application of Geophysical and NDT Methodologies to Transportation Facilities and Infrastructure, St. Louis*.
- Madun, A., Jefferson, I., Chapman, D. N., Culshaw, M. G., Foo K. Y., & Atkins, P. R. (2010a). Evaluation of the multi-channel surface wave analysis approach for the monitoring of multiple soil-stiffening columns. *Near Surface Geophysics*, 8(6), 611-621.
- Madun, A., Jefferson, I., Foo K. Y., Chapman, D. N., Culshaw, M., G. & Atkins, P. R. (2012b). Characterization and quality control of stone columns using surface waves testing. *Canadian Geotechnical Journal*, 49(12), 1357-1368.
- Madun, A., Zainalabidin, M. H., Tajudin, S. A. A., & Haimi, D. S. (2016c). Compressive and shear wave velocity profiles using seismic refraction technique. *Journal of Physics: Conference Series*, 710, 012011, IOP Publishing.
- Madun, A, Supa'at, M. E. A., Tajudin, S. A. A., Zainalabidin, M. H., Sani, S., & Yusof, M. F. (2016d). Soil investigation using multichannel analysis of surface wave (MASW) and borehole. *ARPN Journal of Engineering and Applied Sciences*, 11(6).
- Madun, A, Tajudin, S. A. A., Abdullah, M. E., Zainalabidin, M. H., Sani, S., & Alvin, S. (2016e). Conversion shear wave velocity to standard penetration resistance. *IOP Conference Series: Materials Science and Engineering*, 136(1), 012009, IOP Publishing.
- McDowell, P. W., Barker, R. D., Butcher, A. P., Culshaw, M. G., Jackson, P. D., McCann, D. M., Skipp, B. O., Matthews, S. L., & Arthur, J. C. R. (2002). *Geophysics in engineering investigations*. London: Construction Industry Research and Information Association, CIRIA, 562.
- Matthews M. C., Hope V. S., & Clayton C. R. I. (1995). The geotechnical value of ground stiffness determined using seismic methods. *Geological Society, London, Engineering Geology Special Publication*, 12, 113-123.
- Matthews, M. C., Hope, Y. S., & Clayton, C. R. I. (1996). The use of surface waves in the determination of ground stiffness profiles. *Proceedings of the Institution of Civil Engineers Geotechnical Engineering*, 119: 84-95.
- Moxhay, A. L., Tinsley, R. D., & Sutton, J. A. (January, 2001). Monitoring of soil stiffness during ground improvement using seismic surface waves. *Ground Engineering Magazine*, 34-37.
- Noor, M. A. M., Madun, A., Kamarudin, A. F., & Daud, M. E. (2016). A study of geological formation on different sites in Batu Pahat, Malaysia Based on HVSR method using Microtremor measurement. *IOP Conference Series: Materials Science and Engineering 136(1)*, 012038, IOP Publishing.
- Pan, J. G., Wang, H. B., Li, C., & Zhao, J. G. (2015). Effect of pore structure on seismic rock-physics characteristics of dense carbonate. *Applied Geophysics*, 12(1), 1-10.

