Site Classification using Multichannel Channel Analysis of Surface Wave (MASW) method on Soft and Hard Ground

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Abstract. Site classification utilizing average shear wave velocity (VS(30)) up to 30 meters depth is a typical parameter. Numerous geophysical methods have been proposed for estimation of shear wave velocity by utilizing assortment of testing configuration, processing method, and inversion algorithm. Multichannel Analysis of Surface Wave (MASW) method is been rehearsed by numerous specialist and professional to geotechnical engineering for local site characterization and classification. This study aims to determine the site classification on soft and hard ground using MASW method. The subsurface classification was made utilizing National Earthquake Hazards Reduction Program (NERHP) and international Building Code (IBC) classification. Two sites are chosen to acquire the shear wave velocity which is in the state of Pulau Pinang for soft soil and Perlis for hard rock. Results recommend that MASW technique can be utilized to spatially calculate the distribution of shear wave velocity (VS(30)) in soil and rock to characterize areas.

1. Introduction

Geophysical method enables covered large area of site investigation and tends to be more representative of the site condition compared to the conventional field testing such as borehole. The best geophysical technique to be used at each site is based on the constraints specific to each site, the geological and geotechnical conditions, the project requirements, and geophysical principles. Good correlations have been produced between field test and laboratory tests, which has led to acceptance of field techniques. Cost and time are another constraints to characterize the whole subsurface area. Geophysical method can provide good spatial variability of subsurface characteristics over a site. The principle preferences with each approach are their non-destructive, non-intrusive nature and relative speed of assessment. Among the most widely used geophysical technique is Multichannel analysis of surface waves (MASW) method which presents an attractive alternative to evaluate unknown foundations due to its versatility, speed, and relationship to stiffness properties. MASW method has favourable circumstances over other surface wave method as all seismic wave energy, comprising of both body and surface waves, is recorded by multi-channel receivers. Seismic waves proliferate in the type of body waves and surface waves. The distinction between the two is that body waves are normally non-dispersive. MASW consists of analysing the dispersive nature of surface waves generated from a seismic source on the ground surface (typically an impact from a sledgehammer) and recorded with an array of geophones to determine the variation of shear-wave (S-wave) velocity with depth. Dispersion refers to the fact that the different frequency components in the input surface wave sample different depths of the subsurface strata and will therefore travel at
different velocities. Raw waveforms recorded from geophones placed on the surface can be post-processed to estimate a velocity-frequency relationship (i.e., dispersion curve) that summarizes the dispersion at the site. This curve can then be used in an inversion algorithm to estimate the most probable subsurface stiffness profile capable of generating the measured dispersion curve. [6][7][8][9][10][11][12][13][14]

2. Study area description
This study was carried out by obtaining shear wave velocity from two different geological sites which is at Engineering Campus of Universiti Sains Malaysia (USM), Nibong Tebal, Pulau Pinang for soft soil data acquisition and at Campus Pauh, Universiti Malaysia Perlis (UNIMAP), Perlis for hard rock data acquisition.

2.1 Soft soil data acquisition site
The site situated inside the USM Engineering campus which situated along the west cost of the peninsular Malaysia in the Nibong Tebal, South Seberang Prai, Pulau Pinang. As per the geology map of Peninsular Malaysia (Fig 1), the soil along the west shore comprises of marine and continental deposits, for example mud, residue, sand, and peat with minor gravel content. The exploration territory which situated inside the limit of Penang and Perak States was already a mangrove region. In view of the quaternary geology report, the exploration zone belongs to Gula Formation. The lithology of the Gula Formation is portrayed as sand, silt, dirt, clay, gravel, and a little measure of peat. Residue were fluvially kept in estuaries and littoral zones, which shallower decades back.

Figure 1. Geological Map of Peninsular Malaysia showing the study area.
2.2 Hard rock data acquisition site
The study area is in south bound of the Perlis state with two neighbouring towns, Changlun and Arau. The study area is situated close to the Syed Sirajuddin Areeb Putra Sports Complex, UNIMAP Kampus Pauh, Perlis.

Based on the Geological Map of Peninsular Malaysia (Fig 2), the lithology are limestone, shale, sandstone, and siltstone. From the quaternary geology report, the research area situated in Kubang Pasu formation. The Kubang Pasu formation is mainly composed of mudstone of various colours interbedded with quartz and feldspathic sandstone. There appears to be a continuous succession in Perlis, where clastic strata are sandwiched between Setul Group in the west (Setul boundary range) and the Chuping Hills in the east.

![Figure 2. Geology of Perlis and north Kedah, Northwest of Peninsular Malaysia.](image)

3. Methodology
MASW method were divided into passive and active method of data acquisition. In this study, active method was used to acquire shear wave velocity data. Basically, for active method, 24 geophones are lined up in a straight line on the surface of the test site following the spread configuration in Table 1. As the geophones only record vertical motion, it is important that they are placed vertically on the ground. Active surface waves method measure surface waves generated by dynamic sources such as sledgehammer and the seismograph. When the impact source (sledgehammer) generated a source, the signal will be sent to the seismograph to tell it to start recording. Active MASW utilizes surface waves mainly Rayleigh waves. Offset was set at 5, 10, and 15 m from the first geophone with five time stacking to improve signal-to-noise ratio (SNR) which were adopted from the conventional...
seismic refraction method. The produced impact would generate surface waves, which would be detected by the geophones. The wave form appeared in the seismograph and scattering picture in the Rayleigh basic mode. The data acquisition parameters were summarized in Table 2 for active MASW.

Table 1. Set up of geophones according to spread configuration

| Spread configuration       | Spacing (m) | Offset (strike source) (m) |
|---------------------------|-------------|----------------------------|
| Linear with 24 geophones  | 1.5         | 5, 10, and 15              |
|                           | 3           |                            |

Table 2. Active acquisition parameters.

| Parameter                  | Settings                      |
|----------------------------|-------------------------------|
| Spread configuration       | Linear                        |
| Geophones interval         | 1.5 m and 3.0 m               |
| Total number of geophones  | 24 geophones                  |
| Geophone type              | 4.5 Hz (Vertical)             |
| Nearest offset             | 5, 10 and 15 m                |
| Source equipment           | 7.2 kg sledgehammer            |
| Sample interval            | 0.5 milliseconds              |
| Record length              | 1 second                      |
| Stacking limit             | 5 stacking                    |

Acquired MASW data were processed and interpreted using SeisImager/SW software to determination of shear-wave velocity, \( V_s \) by developing the dispersion curve. The general data processing flows were summarized in three major steps: (i) filter the wiggle plot to the analysable range of frequency of R wave; (ii) develop the dispersion curve of R wave phase velocity and; (iii) inversion of the dispersion curve to obtain the \( V_s \) profiles. The filter and the development of dispersion curve process were carried out by using SeisImager/SW software. The general processing flows is shown in Figure 3.

![Figure 3. General Data Processing Flow of MASW Method. (Geometrics, 2009)](image)

4. Results and discussion

4.1 Soft soil

MASW is carried out to identify the subsurface profile of the study area indicated the \( V_s \) distribution. Shear wave velocity at USM were analysed by using the SeisImager software to produce the 1-D velocity profile. Figure 4 shows the 1-D shear velocity model obtained from the analysis.
Figure 4. 1-D shear velocity model for soft soil.

Table 3. Summary of MASW results.

| Velocity (m/s) | Material description                                                                 |
|---------------|--------------------------------------------------------------------------------------|
| **50 - 360**  | Ground Type S1 = < 100, Deposit consisting of layer at least 10m thick, of soft clay/silts with high plasticity index (P1>40) high water content. Ground type C = 180 – 360, Deposit of dense or medium dense sand, gravel, or stiff clay with thickness from several tens to many hundreds of metres. |
|               | Class E = < 180, Soft clays                                                         |
|               | Class D = 180 – 360, Stiff Soil                                                     |

4.2 Hard Rock

Shear wave velocity profile obtained from the MASW method and analysed to produce the 1-D shear velocity model. Based on the model, the first 30 mm depth Vs is in the range of 800-950 m/s. Rock subsurface was categorize by depth following the Vs propagation stated in methodology section.
Figure 5. 1-D Shear velocity model for hard rock.

Table 4. Summary of MASW results.

| Velocity (m/s) | Material description                                                                 | Eurocode 8 | NEHRP Site class               |
|---------------|--------------------------------------------------------------------------------------|------------|--------------------------------|
| 900 - 1100    | Ground type A = >800, Rock or other rock-like geological formation, including at most 5 m of weaker material at the surface. |            | Class B = 760 – 1500, Firm and hard rock |

5. Conclusion
Site classification using Multichannel Analysis of Surface Wave as a geophysical method is possible for both soft and hard ground. The shear wave velocity obtained using MASW method is representing the average of the velocity at specified depth across the lateral length of the array. The results show that the subsurface can be classified using the MASW method which can be a good parameter for preliminary works and planning. Borehole or Cone penetration test can be used to validate the results obtained. MASW method has the potential to adapt in subsurface investigation to compliment the intrusive.

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