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Determination of shear wave velocity using multi-channel analysis of surface wave method and shear modulus estimation of peat soil at Western Johore

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Abstract

Shear wave velocity and shear modulus is common for geotechnical and geophysics engineer to determine interaction of soil dynamic properties. Both of the dynamic properties were often related to dynamic loading such as earthquake, moving traffic, machineries and bomb blasting. The study was conducted at western part of Johore such as Parit Sulong and Pontian where deposition of peat soil were exists and recognised as problematic soils to the engineers. This study was carried out to determine the shear wave velocity of peat soil using Multi-channel Analysis of Surface Wave (MASW) method and estimation shear modulus of peat using empirical formula. To use the empirical formula, the density of peat soil was also needed thus using the peat sampler for every 0.5 meter depth to obtain the density. From the MASW test for both test sites, the shear velocity of peat at Parit Sulong is between 40 m/s and 55 m/s until depth of 1.5 m meanwhile at Pontian, the shear wave velocity between 21 m/s and 67 m/s until 2.5 m depth. Using shear velocity, shear modulus of peat were estimated for Parit Sulong are ranged between 1575 kPa – 3514 kPa and Pontian are ranged between 385 kPa – 5117 kPa. The shear velocity and shear modulus of peat are very low due to the unique characteristics of peat soils compared with other typical soil.

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1. Introduction

There are demands of dynamic characteristics in construction, especially that have importance to the society such as roads, bridges, high rise buildings that may affected by dynamic movement of the ground. In the field of earthquake engineering, structures of high society or economic importance, such as nuclear power plants, arch dams, hospitals and (long span) bridges demand for detailed design accounting for dynamic soil–structure interaction [1]. It is most critical and important aspect of geotechnical earthquake problems with identified dynamic soil properties [2].

Basically, there are three main dynamic properties usually used in geotechnical parameter such as the shear modulus (G) and Damping ratio (D) and shear wave velocity (Vs). These parameters are very important for the design structure involving dynamic movement, such as foundation, bridge and roads. It is also an important parameter for site response analysis [3]. If these parameters have been ignored it may cause problems in structural damage and also may cost loss of life. In conventional method, dynamic properties can be determined at the laboratory at high strain using cyclic triaxial, torsional shear, resonant column test and bender element test determine modulus of elasticity, shear modulus, damping ratio and shear wave velocity. Meanwhile in geophysics method, only shear wave velocity that can obtain at low strain which shows dynamic properties in undisturbed and undrained soil conditions.

These dynamic properties are very important characteristics of peat soils since it’s been well known by the engineers as problematic soil due to high compressibility and low shear strength which is very not suitable materials to construct any structures. This problem often faced by the engineers at Sarawak, Malaysia when attempted to construct roads for rural area which covered by very vast peat soil area and have difficulty.

This paper was attempted to determine dynamic characteristics of peat soil such as shear wave velocity (Vs) using Multi-channel Analysis of Surface Wave (MASW) technique and shear modulus using a conversion of shear wave velocity with empirical formula where the density of peat was needed thus the density were calculated after collecting the sample using peat sampler.

2. Literature review

2.1. Peat soils

Peat soil is an organic with content more than 75 %, which caused a lot of problems for construction due to unpredictable behaviour of its properties. Peat soils are formed through accumulation of disposing organic plant and have been preserved under conditions of incomplete aeration and high water content [4]. It’s in the category of problematic soil because having lower shear strength and high compressibility [5]. Peat soil has unique characteristics such as high water content (>200%), high compression, high organic content (>75%), low shear strength (5-20kPa) and low bearing capacity (<8 kN/m2) [4]. Peat poses serious problems in construction due to its long-term consolidation settlements even when subjected to a moderate load. It is generally considered that peat soil is not suitable for supporting foundations or loadings in its natural state [6].

The reason is it’s considered as geotechnical problematic where caused slip failure, local sinking, and massive primary and long term settlement when load was applied moderately due to their low shear strength and high compressibility [7]. at Wester Johore, the peat soil was categorised from H5 - H6 which is moderately decomposed peat which a very indistinctly plant structure according to the degree of humidification [8, 13].

2.2. Multi-channels analysis of surface wave

Multi-channel Analysis of Surface Wave is famous and well-known by the researchers to determine shear wave velocity on the field for subsurface characterization. This method using an active source which means seismic energy with intention generated to create seismic waves at specified location along linear direction with spread length [9] then recorded the propagation of surface wave to generate shear wave velocities through fourier transform and inversion dispersion curve of phase velocities in the frequency domain of surface waves since shear wave velocity is superior in surface wave [10]. The shear velocity, soil profile can determine when measure the phase velocity of Rayleigh waves of different frequencies [11].
This method is ideal for effective identification and isolation of seismic noise such as body waves, scattered, and non-source generated surface waves and higher mode of surface waves according to distinctive trace to trace comparison of coherency in arrival time and amplitude. MASW method can take out accurate phase velocities of Rayleigh wave ground roll [12].

3. Geological setting

The location of this study is at Parit Sulong and Mardi, Pontian. These locations consists of peat soil where land for farmers planted pineapple and palm oil trees. By referring geological map of peninsular Malaysia, study location is situated in quaternary region where consist of marine and continental unconsolidated deposits such as peat, humic clay and silt.

4. Methodology

4.1. 1D Multi-channels analysis of surface wave

This method just required three components such as source, recorder and sensor. A 7 kg of sledgehammer was used as seismic source that impacted vertically to the aluminium plate. As recorder, ABEM Terraloc MK-8 seismograph was used which connected with 24 unit of 4.5 Hz vertical geophone is used as sensor. Fig. 1 shows the MASW field acquisition arrangement.

![Fig. 1: MASW field acquisition arrangement.](image)

For record length, it is take time from 2 second until 4 second recording depend on the times requires to observe surface wave at the seismograph. Thus sampling interval need to be adjusted from 250 µs - 500 µs and number of samples is 4096 - 8192. Any filtering of noise turns off to prevent changes in the quality of any noise from the ground. Numbers of background noise record must not stack together. Array line cable is put across the research site with a length of 23 meters long with 1 meter spacing between geophones and offset distance from 1st geophone is 5 meter. The array should be linear as possible depend on the site geometry area. For the geophone should be placed in a clear area and approximately level with the ground. This is to ensure the accuracy of seismic data. For each study location, there are five lines and offset distance between lines is 0.5 meter.

4.2. Determining peat soil density using peat sampler

The density of peat was determined on site were used peat sampler that can obtain peat soil for every 0.5 meters depth. Peat sample has a semi-cylindrical shape after taken from specified depth. To ensure sample disturbance in minimum, the peat sample was measured it’s diameter and length on site, then put into sealed plastic beg to ensure minimum moisture reduction and measured its weight in laboratory. The soil sample was cut approximately 150 mm length and taken from the top part of soil sample for every 0.5 meters. The diameter and length of sample were measured to calculate its volume, then calculate the peat in-situ density after measuring its weight. Peat density determination for each study were repeated for three times to obtain average peat density.

The calculation of peat density is very simple using the basic density formula as shown in equation 1. The volume of peat samples was calculated after measuring the diameter and using semi-circle area formula as show in equation
2 then multiply by the length of samples as shown in equation 3. The mass of samples was measured in unit gram while diameter and length were measured in millimetre then convert into centimetre.

\[ \rho = \frac{M}{V} \]  

Area of semi-circle = \[ \frac{\pi d^2}{4} \]  

\[ \text{Volume} = \frac{\pi d^2}{8} \times L \]  

5. Result and discussion

5.1. Shear wave velocity soil profile of peat

Surface wave seismic data were exported from seismograph then process it using SeisImager software. The software was divided into two modules such as Pickwin module and WaveEq module. This software is specifically used for determination dispersion curve of surface wave of phase velocity in frequency domain and then shear velocity profile in the 1-D image. As shown in fig. 2 the shear velocity profile peat until a depth of 1.7 m at Parit Sulong and 2.5 m depth at Pontian which have been verified using peat sampler profiles. From figure 2 shows that the shear wave velocity of peat at Parit Sulong is between 40 m/s and 55 m/s until depth of 1.5 m meanwhile at Pontian, the shear wave velocity between 21 m/s and 67 m/s until 2.5 m depth.

![Fig. 2: Shear wave velocity profile of peat.](image)

5.2. Shear modulus estimation

After obtaining the shear velocity profile of peat, shear modulus of peat have been estimated using the formula and obtained the in-situ density of peat as shown in Table 1. In geophysical theory, shear modulus related to shear velocity as shown in equation 4. From the equation 4, it’s show shear velocity is directly proportional with maximum shear modulus. Thus maximum shear modulus will increase if shear velocity also increase.
\[ G_{\text{max}} = \rho V_s^2 \]

Where \( G_{\text{max}} \) is small-strain shear modulus and \( \rho \) is density of soil

Table 1. Density, shear wave velocity and Shear modulus of peat soil.

| Depth (m) | Density (g/cm\(^3\)) | \( V_s \) (m/s) | \( G_{\text{max}} \) (kPa) |
|----------|-----------------------|----------------|-------------------------|
|          | Parit Sulong | Pontian | Parit Sulong | Pontian | Parit Sulong | Pontian |
| 0        | 0.94        | 0.89    | 40 - 55     | 21 - 42   | 1575 - 3062 | 385 - 1568 |
| 0.5      | 0.99        | 1.01    | 42 - 54     | 36 - 53   | 2176 - 3514 | 1342 - 2868 |
| 1        | 0.85        | 1.13    | 46 - 55     | 52 - 62   | 2447 - 3473 | 3037 - 4326 |
| 1.5      | 1.17        | 1.13    | 41 - 50     | 42 - 67   | 2066 - 3131 | 2026 - 5117 |
| 2        | 1.72        | 1.20    | 44 - 54     | 35 - 51   | 2299 - 3575 | 1457 - 3183 |
| 2.5      | 1.62        | 1.30    | 32 - 59     | 24 - 45   | 1240 - 4301 | 729 - 2630  |
| 3        | 1.48        |        | 30 - 43     |          | 1328 - 2692 |            |

From fig. 2 show s-wave velocity of peat from Parit Sulong and Pontian have different values for every 0.5 meter depth. This soils s-wave velocity variation is may due to the non-homogenous soil structure of peat soil. The changes s-wave velocity may due to heterogeneity of peat where commonly peat in Malaysia consists of loose, partly decomposed leaves, branches, twigs and tree trunks with a low mineral content [4]. Even when the density peat were calculated, it’s show inconsistent value for every depth due to its difference in decomposition period.

From table 1, shear modulus of peat for Parit Sulong are ranged between 1575 kPa – 3514 kPa and Pontian are ranged between 385 kPa – 5117 kPa. The difference of peat shear modulus may due to the difference with their degree of composition and variation of organic content and fiber content. Higher content of organic and fiber can contribute to the higher shear modulus of peat since the arrangement of organic structure is more compacted than low organic content and fiber content of peat. Degree of composition also have their affect on shear modulus as more decomposed peat usually compressed easily when induced with load which indicated low strength to withstand heavy load. Comparison of shear modulus from field estimation were higher than the shear modulus obtained from the laboratory where researcher Adnan and Aini [13] determined shear modulus of Western Johore peat using cyclic triaxial test were ranging from 100 kPa – 1150 kPa. The differences of field estimated shear modulus and laboratory testing due to the strain applied to the sample since field testing using strain < 0.001% while laboratory testing use > 0.01% [14].

6. Conclusion

In this study, the determination of shear wave velocity for peat was used multi-channel analysis of surface wave (MASW) method and meanwhile shear modulus value was by using empirical formula. A study was conducted at Parit Sulong and Pontian. Shear velocity of peat at Parit Sulong is between 40 m/s and 55 m/s until depth of 1.5 m meanwhile at Pontian, the shear wave velocity between 21 m/s and 67 m/s until 2.5 m depth. Using shear velocity, shear modulus of peat were estimated for Parit Sulong are ranged between 1575 kPa – 3514 kPa and Pontian are ranged between 385 kPa – 5117 kPa. Changes of shear wave velocity and shear modulus due to the non-homogenous soil structure of peat soil. Field estimated shear modulus higher than the laboratory shear modulus of peat due to the strain applied to the sample.
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