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Establishment of Dynamic Properties for Malaysian Peat Soil Using Multichannel Analysis of Surface Waves

Adnan Zainorabidin[1,2]*, Kasbi Basri[1,2], Koh An Ang[3], Habib Musa Mohamad[4], Mohd Khaidir Abu Talib[1,2], Zeety Md Yusof[1,2], Faizal Pakir[1,2], Amirzaki Salikin[1,2]

[1] *Faculty of Civil Engineering and Built Environment, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA*
[2] *Research Center for Soft Soil, Universiti Tun Hussein Onn Malaysia, 86400 Parit Raja, Batu Pahat, Johor, MALAYSIA*
[3] *GDS Instruments Sdn. Bhd, 124, Jalan Kapar, 27/89, Taman Alam Megah, 40400 Shah Alam, Selangor, MALAYSIA*
[4] *Faculty of Engineering, Universiti Malaysia Sabah, Jalan UMS, 88400 Kota Kinabalu, Sabah, MALAYSIA*

*Corresponding Author: adnanz@uthm.edu.my
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Abstract

A poor understanding of peat behavior has introduced several engineering problems including differential settlements or slides which greatly impact society. Problematic characteristics of peat including a high moisture content and the presence of fresh fibers, cause a significant challenge in obtaining high-quality samples for laboratory-based investigation. Therefore, the application of in-situ geophysical methods is sought to mitigate these problems. The dynamic properties of a peat deposit in West Malaysia are described in this study. The Multichannel Analysis of Surface Waves (MASW) was conducted at six different locations. These peat soils had considerably different characteristics due to the different natures of decomposed materials. The samples obtained from the five locations had organic contents of 66.5 to 97.1%, water contents of 447 to 964%, and fiber content between 22.1 and 75.2%. Based on Von Post classification, the peat type ranged from H3 (fibrous) to H8 (amorphous). Shear wave velocity (V_s) and maximum shear modulus (G_{max}) are presented, and their dependence on variables such as moisture content, organic content, fiber content, specific gravity and bulk density are illustrated. The general trend shows an increase in V_s and G_{max} with decreasing moisture, organic and fiber content of peat soil. The difference in the degree of humification did not result in significant differences in V_s and G_{max} obtained. The results showed that the value of V_s and G_{max} ranged from 24.0 to 67.1m/s and 0.40 to 7.06 MPa respectively. Correlation between the index and dynamic properties peat shows that the V_s and G_{max} increase as the moisture, organic and fiber content decreases. Successful determination of in-situ V_s and G_{max} on peat soil minimized the potential of underestimation due to sample disturbance and provide a sustainable, rapid and economic method.

1. Introduction

Peatlands are well known to be extremely challenging for construction in Malaysia. As stated by Jon et al. [1], the distribution of peatlands in Malaysia is approximately 2.46 million hectares which is the 9th largest in the world. Peat is considered challenging due to its characteristics including very high water content, high organic content, high compressibility and low shear strength [2]. Among the popular problems related to construction on peat include bearing capacity failure and large consolidation settlement [3], and serious structure and embankment damage due to dynamic issues [4]. Investigation of the dynamic properties of peat is commonly conducted in the laboratory, but risk inaccuracy due to stress relief, the scale factor of the sample size and sample disturbances during transportation and handling in the laboratory [5]. Moreover, due to the very high moisture content and the presence of fresh fibers in peat, sample collection is challenging as in most cases the recovery ratio was lower due to the disruption caused by the fresh fibers. The difficulties to retrieve good quality samples causes limited data available on the dynamic properties of peat despite its importance and causes many issues regarding peat to remain unknown in comparison with those of inorganic soil such as sand and clay [6]. Some of the studies related to the dynamic properties of peat include Ireland, Scotland, the Netherlands, and Sweden peat [7], Holocene peat [8], Hokkaido peat [4], Malaysian peat [9, 10].

In recent years, the rapid development of geophysical methods in geotechnical investigation has provided alternative methods to determine the soil's dynamic properties. For example, the Multichannel Analysis of Surface Waves (MASW) method is able to determine the peat dynamic properties in-situ and mitigate the risk of sample disturbance from undisturbed sample collection. According to Seed and Idriss [11], in-situ testing mitigates the risk of inaccurate data due to sample disturbance caused by boring, tube insertion, transportation, storage, extraction, trimming and reconsolidation. MASW method is also non-intrusive, time efficient and investigates larger areas in a single test providing a sustainable alternative compared to the conventional drilling method. Furthermore, the comparison between the MASW method with the other methods was very promising. Xia et al. [12] and Xia et al. [13] proved that the difference between the Vs determined using MASW and borehole was less than 15%. Moffat et al. [14] found that the result between MASW, downhole test and bender element gives an almost similar result. Oh et al. [15] compared the results from the MASW and downhole test with only a 9% discrepancy.

2. Materials and Methods

The study was conducted at Parit Nipah (PNPt), Tanjung Piai (TPPt), Pontian (PPt), Sedenak (SPt), Medan Sari (MSPt) in West Malaysia, and Klias (KPt) in East Malaysia. The peat thickness in these locations varies from 1.5 to 6.8 m. The underlain layer was determined as the marine clay for all locations. The peatland in the study area is mainly used for pineapple and palm oil plantations. The determination of index properties of peat focused on the essential parameter stated by O'Kelly [16], including the degree of humification, moisture content, fiber content and organic content. The peat samples and bulk density were obtained using the Eijkelkamp peat sampler for every 0.5 m depth. The procedure for the sample retrieval using the peat sampler follows the guideline provided by Eijkelkamp Agrisearch Equipment [17]. The determination of moisture content, organic content and fiber content follows the guideline stated in BS1377. Meanwhile, the degree of humification was defined using the Von Post classification method [18].

The investigation using Multichannel Analysis of Surface Waves (MASW) follows the guideline provided by Park et al. [19]. The entire process consists mainly of three steps: acquisition of ground roll, construction of dispersion curve (a plot of phase velocity versus frequency) and back-calculation (inversion) of the shear wave velocity (Vs) profile from the calculated dispersion curve [19]. Application of the MASW method on peat required slight modification on the present guideline due to peat characteristics. As mentioned by Basri et al. [20] and Basri et al. [21] high moisture content and low shear strength of peat causes inconsistent and weak seismic energy generated. Therefore, additional guidelines especially for peat provided by Basri et al. [20] and Basri et al. [21] were followed. Fig. 1 shows the general layout for the field configuration of the MASW method.

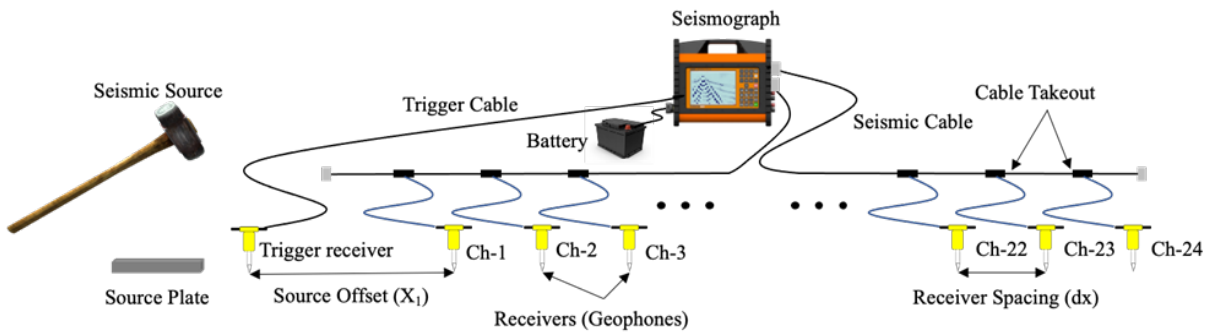


Fig. 1 *The general layout of active MASW field configuration*

ABEM Terraloc MK8 was used as a seismograph powered by a 12-volt battery. A total of 24 geophone receivers with 4.5 Hz natural frequency were connected to the seismograph via Lund imaging cable. The receiver spacing (dx) was 1 m producing a total spread length (L) of 23 m. A 7 kg sledgehammer and rubber plate were used as the active source with a source offset distance (X_1) of 11.5 m (half the total spread length). The rubber plate was used to improve the generated seismic signal [20, 21]. A total of 5 stackings for each dataset was used to ensure high signal-to-noise data was obtained. For each location, 6 survey lines were investigated excluding Klias. At Klias, 3 survey lines were investigated at each of the three stations with a total of 9 survey lines. The maximum shear modulus (G_{max}) was then computed using the relationship between bulk density and V_s as shown by Equation 1.

$$G_{max} = \rho V_s^2 \quad (1)$$

Where ρ is bulk density, V_s is shear-wave velocity and G_{max} is the maximum shear modulus.

3. Index Properties of Peat Soil

The index properties were determined for every 0.5 m for correlation with the dynamic properties. Table 1 summarized the index properties determined at all study locations. The investigation revealed that the degree of humification differs for every study location. Based on the Von Post classification, Parit Nipah (PNPt), Tanjung Piai (TPPt), Pontian (PPt) and Klias (KPt) were classified as moderately decomposed peat (H5-H6). Meanwhile, Sedenak (SPt) and Medan Sari (MSPt) were classified as highly decomposed (H8) and slightly decomposed (H3) respectively. The moisture content recorded was significantly higher for slightly decomposed peat compared to highly decomposed peat. A similar pattern was observed for the organic content and fiber content, where a higher value was recorded for the slightly decomposed peat and decreased as the peat become significantly decomposed. The moisture content, organic content and fiber content determined were ranging from 425 to 985 %, 54.0 to 97.1 % and 22.1 to 75.2 % respectively.

Table 1 *Summary of index properties of peat*

Location	Degree of humification	Moisture content, w (%)	Organic content, OC (%)	Fibre content, FC (%)
PNPt	H6	447-848	74.1-86.1	41.7-58.8
TPPt	H5	542-890	75.8-89.2	44.5-62.1
PPt	H5	589-868	76.5-88.6	43.4-60.8
SPt	H8	425-717	66.5-80.8	22.1-30.6
MSPt	H3	642-964	84.9-97.1	67.8-75.2

4. Dynamic Properties of Peat Soil

The shear wave velocity (Vs) of peat was determined using the Multichannel Analysis of Surface Waves (MASW) at Parit Nipah (PNPt), Tanjung Piai (TPPt), Pontian (PPt), Sedenak (SPt), Medan Sari (MSPt) and Klias (KPt). The Vs value obtained ranges from 26.7 to 38.2 m/s, 24.8 to 34.5 m/s, 24.4 to 35.4 m/s, 24.3 to 34.5 m/s 24.0 to 35.4 m/s and 27.4. to 67.1 m/s for PNPt, TPPt, PPt, SPt, MSPt and KPt respectively. Fig. 2 illustrates the Vs profiles obtained at all locations. From the figure, the Vs. values increase only slightly at the top 3 meters. The behavior was governed by a high water table and low bulk density recorded on site. The water table obtained at the study locations was approximately 0.5 from the surface and the bulk density were ranging from 0.73 to 1.53 g/cm3.

According to Huat [22], high water table and low bulk density imply low effective stress with depth, thus there may not be a discernible increase in strength with depth. Meanwhile, at a depth greater than 3 meters the increase of Vs value became significant which was attributed to the increase of effective stress near the transition layer between peat and soft clay. As mentioned by L'Heureux and Long [23], an increase in the effective stress of soil contributed to an increase in Vs. Moreover, the peat layer near the surface has a lower decomposition rate and increases with depth. A lower decomposition rate reflects a higher void ratio, thus a lower strength [24]. According to Seed and Idriss [11], lower strength and stiffness are associated with lower Vs.

From the Vs obtained, the maximum shear modulus (Gmax) was computed using Equation 1. The bulk density obtained for PNPt, TPPt, PPt, SPt, MSPt and KPt were ranging from 0.73 to 1.26 g/cm3, 0.72 to 1.25 g/cm3, 0.77 to 1.43 g/cm3, 0.67 to 1.22 g/cm3, 1.09 to 1.41 g/cm3 and 0.98 to 1.53 g/cm3 respectively. Overall, the Gmax obtained showed a slight increase with depth (see Fig. 3). A similar finding was observed by Donohue et al. [25] where the stiffness modulus increases with depth. The peat properties also showed increasing effective stress, governed by decreasing void ratio with depth. According to Matthews et al. [26], increases in effective stress and the degrading effects of weathering cause an increase in stiffness. Furthermore, a decrease in moisture and organic content causes the Gmax to increase [27]. The Gmax determined for PNPt, TPPt, PPt, SPt, MSPt and KPt were ranging from 0.55 to 1.68 MPa, 0.47 to 1.40 MPa, 0.48 to 1.65 MPa, 0.4 to 1.45 MPa, 0.69 to 1.68 MPa and 0.76 to 7.06 MPa correspondingly. The findings were in good agreement with the previous researchers, 0.39 to 5.12 MPa [28], 0.5 to 1.7 MPa [29], 0.74 to 11.27 MPa [10], 1.01 to 6.83 MPa [9] and 1.5 to 12.3 MPa [6].

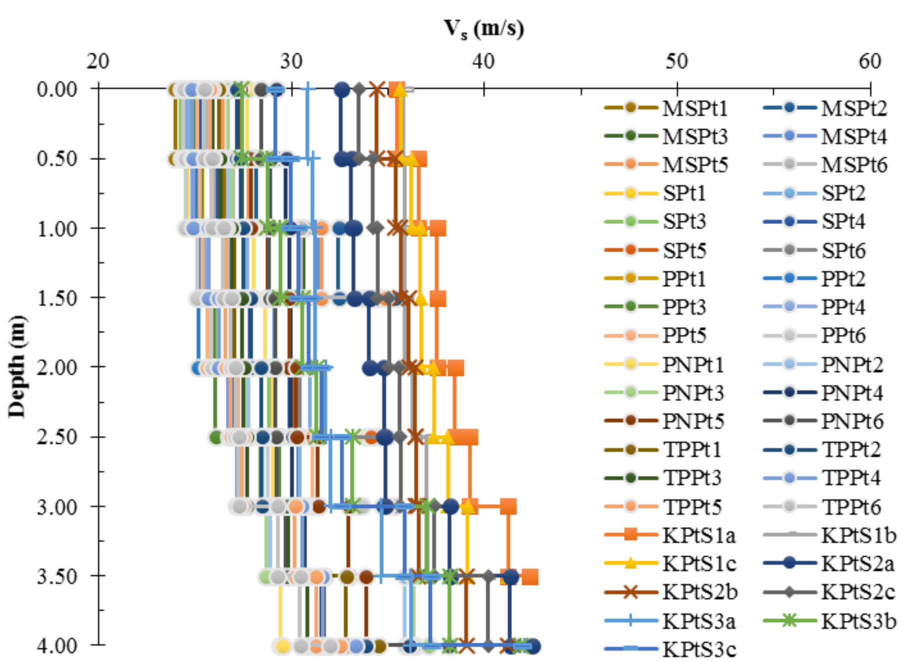


Fig. 2 *The shear wave velocity profiles*

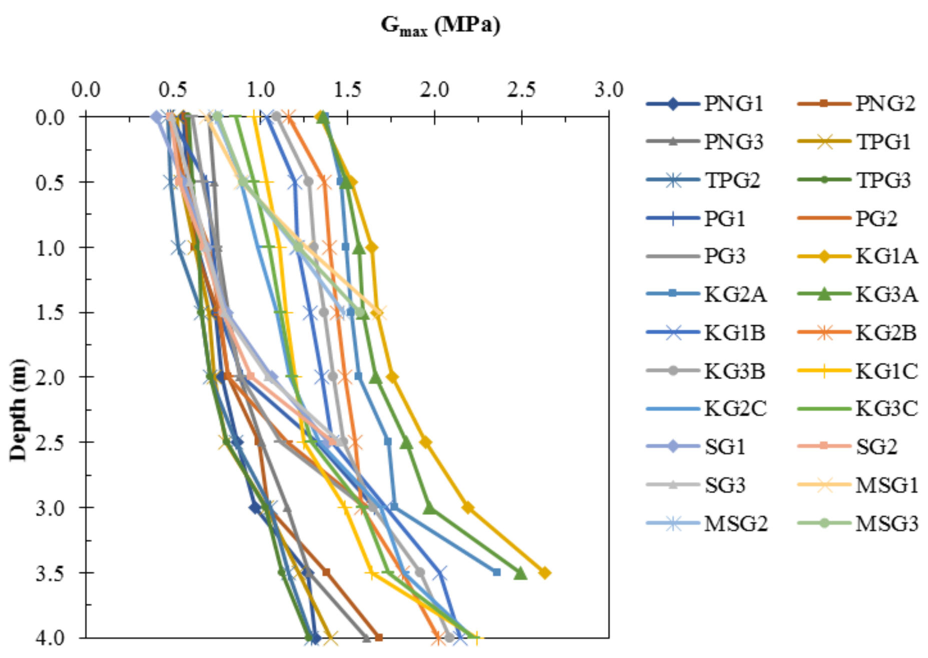
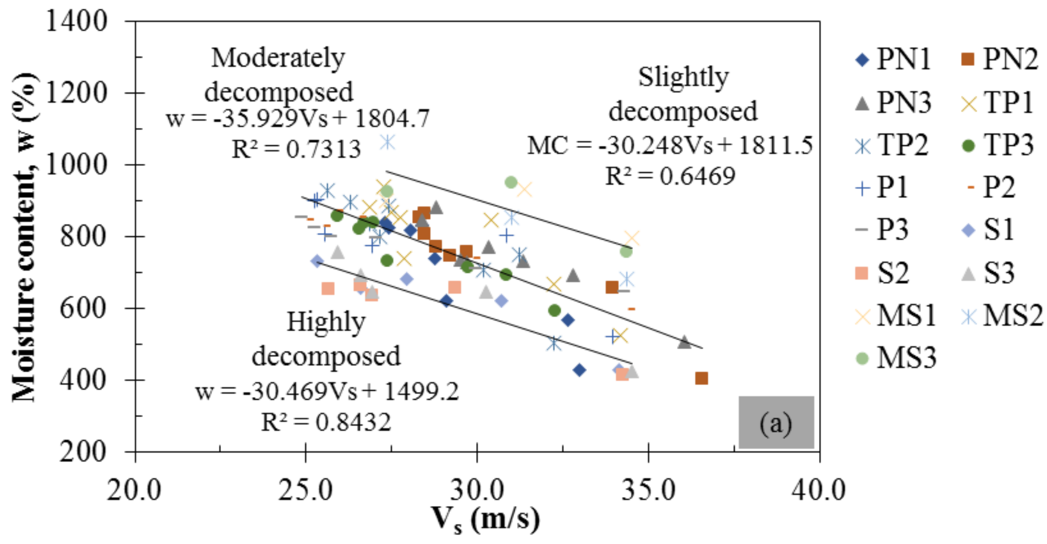
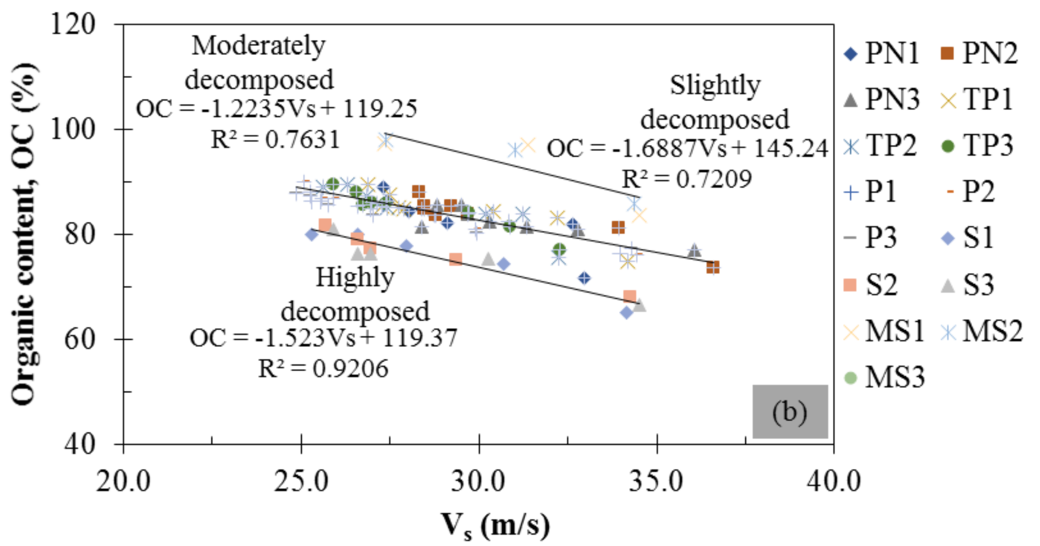


Fig. 3 *The maximum shear modulus profiles*

5. Correlation Between Index and Dynamic Properties of Peat Soil

Furthermore, the influence of peat properties including moisture, organic and fiber content on the dynamic properties was observed. Early observation revealed a scattered pattern in the correlation between the index and dynamic properties of peat. The behavior might be governed by the heterogeneity of peat. According to Koster et al. [30], peat property varies laterally and vertically, governed by the organic matter content. Furthermore, the degree of decomposition had a significant influence on peat behavior. O'Kelly and Zhang [31] also mentioned that, depending on the degree of humification, the organic solids in peat can exist as fresh fibers, slightly decomposed or ultimately decomposed material and different levels of degree of humification significantly influenced the peat behavior. Therefore, the correlation was separated into different degrees of decomposition, and the correlation was improved significantly. Thus, the correlation was separated into three groups: (a) slightly decomposed peat, (b) moderately decomposed peat and (c) Highly decomposed peat. Fig. 4 and 5 illustrates the correlation between the index and dynamic properties of peat.





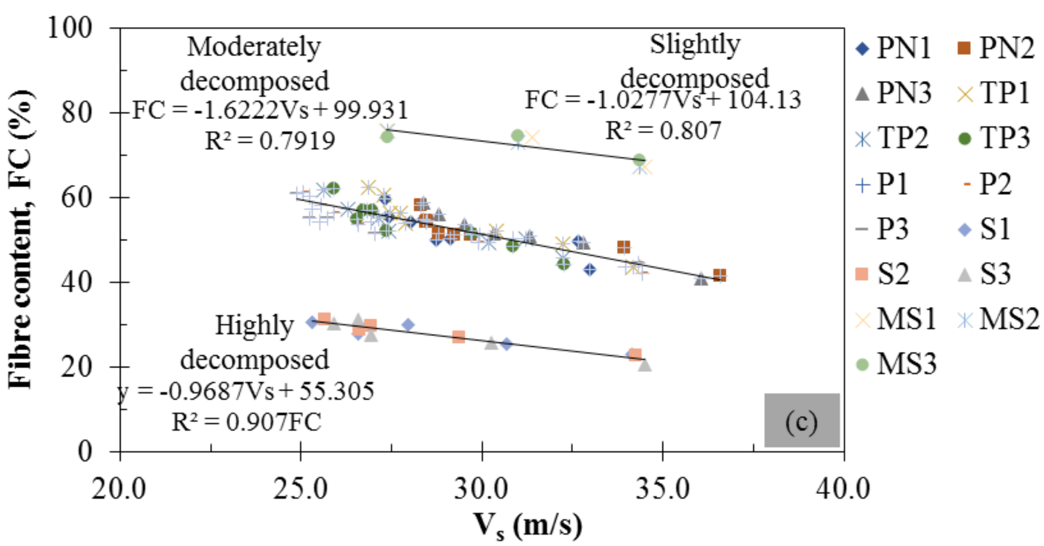


Fig. 4 *Shear wave velocity, V_s against (a) Moisture content; (b) Organic content; and (c) Fiber content of peat soil*

Generally, the V_s and G_{max} increase as the moisture, organic and fiber content decreases. High moisture content contributed to a high void ratio which reflects low strength in peat [24]. L'Heureux and Long [23] and Long *et al.* [32] also concluded that the V_s and G_{max} increase with decreasing moisture content. Similarly, high organic content and fiber content were also attributed to a high void ratio. The lower the void ratio the higher the strength, thus the stiffer the peat. Kishida *et al.* [33] mentioned that lower organic content tended to have higher V_s and G_{max}. Meanwhile, L'Heureux and Long [23] and Yang and Liu [34] concluded that decreasing fiber content results in a lower void ratio, thus, contributing to higher V_s and G_{max}.

6. Conclusion

The in-situ determination of the dynamic properties of peat mitigated the sample disturbance problems which resulted in higher accuracy data. The testing conducted in the peat natural condition also minimized the underestimation due to the failure to replicate the natural ground condition of the undisturbed samples in the laboratory. The shear wave velocity (Vs) of peat at Parit Nipah (PNPt), Tanjung Piai (TPPt), Pontian (PPt), Sedenak (SPt), Medan Sari (MSPt) and Klias (KPt) ranges from 26.7 to 38.2 m/s, 24.8 to 34.5 m/s, 24.4 to 35.4 m/s, 24.3 to 34.5 m/s 24.0 to 35.4 m/s and 27.4. to 67.1 m/s respectively. Meanwhile, the maximum shear modulus (Gmax) of peat determined for PNPt, TPPt, PPt, SPt, MSPt and KPt ranged from 0.55 to 1.68 MPa, 0.47 to 1.40 MPa, 0.48 to 1.65 MPa, 0.4 to 1.45 MPa, 0.69 to 1.68 MPa and 0.76 to 7.06 MPa correspondingly. Both the Vs and Gmax of peat were very low due to very high water content and low bulk density. The increasing pattern of Vs and Gmax was attributed to the decreasing void ratio and increasing effective stress with depth. The findings also revealed that there was a significant influence of moisture, organic and fiber content on the Vs and Gmax values. Decreasing moisture, organic and fiber results in higher Vs and Gmax. Despite the scattered pattern between the index properties and dynamic properties, the correlation was useful to provide an early estimation of the dynamic properties of peat from the index properties. Overall, the MASW method provides a sustainable, rapid and economical alternative to determine the dynamic properties of peat.

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Conflict of Interest

There is no conflict of interests regarding the publication of the paper.

Author Contribution

The authors confirm contribution to the paper as follows: ***study conception and design:*** *Adnan Zainorabidin, Koh An Ang, Habib Musa Mohamad, Mohd Khaidir Abu Talib, Zeety Md Yusof, Faizal Pakir;* ***data collection:*** *Kasbi Basri, Amirzaki Salikin;* ***analysis and interpretation of results:*** *Kasbi Basri;* ***draft manuscript preparation:*** *Kasbi Basri. All authors reviewed the results and approved the final version of the manuscript.*

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