Influence of Source Energy and Stacking on Active MASW Method Dispersion Image

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Abstract. The study investigates the influence of source weight, type of source plate and number of stacking on the resolution of the dispersion image obtained from the active Multichannel Analysis of Surface Waves (MASW) method at peat soil condition. Fundamental-mode dispersion curve determination is governed by the optimum configuration of the active MASW method. Optimum configuration will ensure reliable inverted shear wave velocity profile. The heterogeneity and problematic characteristics of peat soil provide challenges on the MASW survey. Based on the field tests conducted, the effect of the source weight was significant. Heavier source weight relatively increases the dispersion image resolution especially at lower frequencies but sacrificing the resolution at higher frequencies. Therefore, heavier source weight (i.e. 7 kg sledgehammer) was recommended for deeper depth of investigation with little concern on the shallow depth. The use of rubber plate also contributed to the increases of energy accumulation at lower frequencies. Increasing number of stacking increases the overall energy band as the stacking allows significant suppression of the ambient noise. 5 to 10 stacks were recommended for peat soil condition. Finally, overall comparison between the dispersion images obtained at both locations shows that thicker peat soil layer results in lower resolution and low signal-to-noise ratio dispersion image.

1. Introduction
Multichannel Analysis of Surface Waves (MASW) was first introduced by the Kansas Geological Survey (KGS) in the late 1990s [1]. Since its introduction, this method had been applied in subsurface explorations for various geotechnical engineering projects. Compared to other surface waves method, MASW is considered superior due to the ability to measure multi-receiver in a single test, thus, exploits multichannel recording and processing technique. Recently, several doubts were raised on the influence of field configurations on the shear wave velocity profile obtained. L’Heureux and Long [2] and Ivanov et al. [3] mentioned that, source strength, receiver spacing, source offset distance, array length, frequency content and sampling time can all influence the shear wave velocity results. Park and Carnevale [4] found that the importance of source offset had been previously underestimated. Sauvin et al. [5], Roy and Jakka [6] concluded that source offset distance could cause underestimation and overestimation, whereas Sauvin et al. [5] stated that maximum wavelength is governed by source energy and area of impact. Thus, investigation on the optimum configuration is critical to ensure high resolution dispersion image and accurate shear wave velocity profile, as the determination of optimum...
configuration can improve the resolution and quality of the shear wave velocity profile [3]. The most commonly adopted method to determine suitable configuration of MASW method is by theoretical recommendations. However, it is widely accepted that the optimum configuration is site dependant. Ivanov et al. [3] suggested that, the optimum acquisition and processing MASW parameters selection are to be achieved using field tests compared to theoretical recommendations.

Present studies on the optimum configuration focused mainly on the stiffer materials and very less on soft soil such as peat soil. The application of MASW method on peat soil investigation had gained increasing popularity due to the ability of the method to test the soil in its natural state. Peat soil is considered challenging soil due to its problematic characteristics. According to Zainorabidin and Wijeyesekera [7], the challenging features of peat includes a high water content (>200%), high compressibility, high organic content (>75%), low shear strength (5-20kPa) and low bearing capacity (<8 kN/m²). Peat soil is also heterogeneous, very soft and spongy which creates difficulties to investigate using conventional boring method. According to Basri et al. [8], peat soil properties could affect the shear wave velocity value. MASW method allows the measurement of soil in its natural state, thus, mitigating the effect of sample disturbance from drilling, tube insertion, extraction, transportation, storage, trimming and reconsolidation [5]. Therefore, investigation on the optimum configuration of MASW method on peat soil condition is important to ensure high accuracy data determined. Thus, this study focused on the investigation of the influence of different source weight, type of source plate and number of stacking on the dispersion image obtained from the active MASW survey.

2. Materials and methods

2.1. Location of the study area
The study was conducted at Parit Nipah and Pontian, Johor. The areas are located within the quaternary region which consist of marine and continental deposits such as clay, silt, sand, peat with minor gravel. Figure 1 shows the locations of the study area. Soil profiling made in these areas using peat sampler delineated that the top 4 meters and 1.5 meters of the soil layer for Parit Nipah and Pontian respectively are peat soil layer followed by the marine clay layer.

![Figure 1. Location of study area.](image-url)
2.2. Multichannel Analysis of Surface Waves (MASW) method
The entire process of MASW method mainly involved 3 steps; (i) acquisition of ground roll, (ii) construction of dispersion curve (a plot of phase velocity against frequency) and (iii) back-calculation (inversion) of the $V_s$ profile from the calculated dispersion curve [1]. The field configuration for the MASW test consists of 24 units of geophone receivers assembled in the linear array connected to the geophone cable. The signal was recorded by the ABEM Terraloc MK8. The receiver spacing (dx) and nearest offset ($X_1$) used were 1 meter and 11.5 meters respectively for all the tests. Three type of source weight which are 7 kg sledgehammer, 1.5 kg steel hammer and 0.5 kg rubber hammer were used to generate impact energy. While, for the source plate, rubber plate and steel plate were used as the impact absorber. The seismograph configuration for the sampling time interval and number of samples were 100-250 $\mu$s and 16384 respectively. For data analysis, SeisImager was used to select the best pick point in the dispersion curve while the WaveEq was used to produce the 1-D MASW model and generate the $V_s$ profile.

3. Results and discussions
The weight of the impact sources and the types of source plates are related to the signal-to-noise ratio and the depth of investigation. In this study, 7kg sledgehammer, 1.5 kg steel hammer and 0.5 kg rubber hammer were used as the impact source. While, steel plate and rubber plate were used as the source plates. The dispersion images obtained are grouped into two categories according to the types of source plates used. Figure 2 (a-c) and Figure 3 (a-c) shows the dispersion images obtained using steel plate meanwhile Figure 2 (d-f) and Figure 3 (d-f) using rubber plate. The results pointed out that, the increase of source weight significantly improved the accumulation energy of dispersion trend of the fundamental mode especially at the lower frequencies using both types of source plates. Thus, it eases the plotting of dispersion curve especially at lower frequencies. The finding was in good agreement with Taipodia and Dey [9] which obtained that, the heavier weight produced higher resolution dispersion image and larger depth of investigation. On the other hand, at higher frequencies the energy band dropped relative to increment of source weight. The behaviour shows that the increase of source energy improved the amplitude of lower frequencies but sacrificing the amplitude of the higher frequencies. Thus, heavier source weight (i.e. 7 kg sledgehammer) was suggested if the study focused on deeper depth of penetration with minimum concern of the shallow area.

In the case of the type of source plate, higher energy accumulation specifically on the lower frequencies band was observed when using the rubber plate. While, when using steel plate, the energy band was greater on the higher frequencies. This finding suggests that, rubber plate provides better sensitivity to the lower frequencies, while steel plate for the higher frequencies. Taipodia et al. [10] also found that rubber plate produces waves of low frequency content, meanwhile significantly high frequency content was obtained when using steel plate. Similarly, Coe and Asabere [11] found that, ultra-high-molecular-weight (UHMW) and aluminium with rubber improved the resolution and increased the low frequency content present in the dispersion image, providing deeper depth penetration. Therefore, the non-steel source plate such as rubber provide better resolution especially on the lower frequencies. The use of rubber plate on peat soil also minimised the problem encountered as the source plate penetrated into the ground after several impact shots as reported by Said et al. [12]. Compared to the steel plate, the rubber plate was able to withstand almost two to three times more impact shots before penetrated into the ground. Therefore, rubber plate provides more consistent shots for stacking compared to steel plate.

Stacking is a process of combining several dispersion images of various shots to improve the resulting dispersion image. In peat soil area, stacking was challenging as the repeated impact causes the source plate to penetrate into the soil causing inconsistent impact energy. Similar problem was encountered by Said et al. [12] when collecting seismic refraction data on peat area. The results obtained for different stacking numbers for Parit Nipah and Pontian are shown in Figure 4 (a-c) and Figure 5 (a-c) respectively. From the results, the resolution of the dispersion image increased relative to the number of stacking used. As mentioned by Taipodia et al. [13], Neducza [14] and Park and Shawver [15], stacking improved the resolution quality by statistically improving the signal-to-noise ratio and enhanced the accuracy of the extracted dispersion curve. The high number of stacking used provide
Figure 2. Dispersion images obtained using steel plate at Parit Nipah; (a) 0.5 kg rubber hammer, (b) 1.5 kg steel hammer, (c) 7 kg sledgehammer, and using rubber plate; (d) 0.5 kg rubber hammer, (e) 1.5 kg steel hammer, (f) 7 kg sledgehammer.
Figure 3. Dispersion images obtained using steel plate at Pontian; (a) 0.5 kg rubber hammer, (b) 1.5 kg steel hammer, (c) 7 kg sledgehammer, and using rubber plate; (d) 0.5 kg rubber hammer, (e) 1.5 kg steel hammer, (f) 7 kg sledgehammer.
higher accumulation of energy which in return increased the resolution of the dispersion image especially at the lower frequencies. The frequency spectra corresponding to the impact from heavier source shows an energy increases on overall frequency band as the stacking allows significant suppression of the ambient noise [10]. Taipodia et al. [13] recommend that, 3 to 4 stacks are required to generate high resolution dispersion image for softer soil ($V_s < 200\text{m/s}$) and single stack is sufficient for stiffer soil. The authors also mentioned that, increasing the stacking number up to 7 onwards will results in the deterioration of the dispersion image due to noise intrusion. In this case, even up to 10 stacks, the resolution of the dispersion image was still improving although the overall resolution was still low. The low signal-to-noise ratio might be contributed by the peat soil characteristics which include high void ratio and high moisture content which cause the wave energy to be dampened much quicker compared to other types of soil. Further, the inhomogeneity of peat soil also affects the resolution of the dispersion image [16]. Therefore, considering the problem of the source plate penetrated into the ground, 5 to 10 stacks is recommended for investigation on peat soil.

**Figure 4.** Dispersion images obtained using different number of stacking at Parit Nipah; (a) single stack, (b) 5 stacks and (c) 10 stacks.
Figure 5. Dispersion images obtained using different number of stacking at Pontian; (a) single stack, (b) 5 stacks and (c) 10 stacks.

4. Conclusions
The influence of different source weight, types of source plates and number of stacking for active MASW survey on peat soil condition were investigated. The following conclusions can be drawn: (i) the increased of source weight improved the accumulation energy of dispersion trend especially at the lower frequencies. While, at higher frequencies, the energy band dropped slightly relative to increase in source weight energy, (ii) the used of rubber plate provides greater resolution at lower frequencies and minimised the risk of source plate penetrates into the ground on peat soil condition, (iii) high number of stacking provides better dispersion image resolution especially at lower frequencies and improved the overall signal-to-noise ratio. The overall comparison between the dispersion images obtained from Parit Nipah and Pontian shows significant difference of resolution and signal-to-noise ratio. Stronger energy band and higher signal-to-noise ratio were observed on the dispersion image obtained at Pontian compared to Parit Nipah. This behaviour was governed by the difference in peat thickness at both locations. As mentioned earlier, peat soil characteristics cause the wave energy to be dampened much quicker. Thus, thicker peat soil layer contributes to the weaker energy band recorded at Parit Nipah site. Further, the lower resolution and signal-to-noise ratio was also affected by the heterogeneity of peat soil.
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