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The Optimum Field Configuration for Active MASW Survey on Peat Soil

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Abstract: The application of the MASW method on engineering investigation required optimization of the field configuration to ensure high quality dispersion image for reasonable shear wave velocity profile estimation. The limited investigation with respect to peat soil condition has motivated the study to determine the optimum field configuration for peat soil. The challenging characteristics of peat soil including high void ratio, compressibility, water content and low shear strength further complicates the determination of optimum field configurations. The study focused on the determination of optimum field configurations for active MASW method which includes the receiver spacing, source offset, sensor frequency and sampling interval. The results obtained shows that, the optimum receiver spacing to obtain high signal to noise ratio dispersion image was 1 meter. Smaller receiver spacing causes domination of higher modes and wide bandwidth, while longer receiver spacing causes significant drop in signal to noise ratio governed by rapid energy dissipation with distance. For the source offset, the distance of half the total spread length ($X_1 = L/2$) provides the best resolution and minimised near-field and far-field effect. While, 4.5 Hz sensor frequency and sampling interval between 100 to 250 μs provides sufficient low frequencies for deeper depth investigation and denser data. Overall, the influence of receiver spacing, source offset and sensor frequency on the dispersion image resolution was significant.

Keywords: Active MASW survey, peat soil, optimum configuration, dispersion image

1. Introduction

The surface waves method becomes popular and widely used for engineering application in the late 1970s after the introduction of Spectral Analysis of Surface Waves (SASW) [1], [2]. The SASW method uses the two-receivers configuration and straight forward data analysing process providing simplicity in data acquisition and processing. However, the simplicity of the SASW method causes several disadvantages on its application, such as effect of coherent and incoherent noise, distortion of the local phase by higher modes and body waves, and also difficulties in interpretation [3]. In the late 1990s, Multichannel Analysis of Surface Waves (MASW) is introduced by researchers at the Kansas Geological Survey to solve the problems related to the SASW method. The use of multiple receivers in MASW method increases the productivity in the field and accelerate the data processing process. The advantages of MASW method include the ability to take into full account the complicated nature of seismic waves, volumes and lateral continuity in investigation, testing the soil in its natural state, averaging out inhomogeneities, environmentally

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friendly, economic and time efficient [4]-[10]. Despite the advantages in the application of MASW method, several challenges are faced to ensure the quality of the data obtained. One of the main issues is related to the accuracy of the shear-wave velocity (V_s) profile determined. The process which governed the accuracy of V_s profile is plotting the dispersion curve during the data analysis. The most accurate dispersion curve analysis during the subsequent data analysis was assured by the optimum acquisition parameters [11]. Therefore, ensuring high-resolution dispersion image obtained during data collection is critical as it influenced the dispersion curve plotting. According to Park et al. [11] and Ivanov et al. [12], geophone spacing, source distance, total spread length, total sampling time and source frequency content are parameters that can affect the final results. Investigation involving the optimum configuration has grown rapidly throughout different type of soil, but up to date, very minimum was focused on peat soil.

The investigation for optimum configuration on peat soil is very limited due to lack of peat soil investigation using the active MASW method. However, the method has increasingly gain popularity due to the demand of investigating peat soil in its natural state as the sampling procedures on peat soil are challenging. Laboratory based test on peat soil results in overestimation of values obtained due to sample disturbance [13]. The sample disturbance is mainly caused by disruption caused by boring or drilling process, the insertion of tube, sample gathering, sample extraction and transportation [7], [14], [15]. Therefore, the nature of the active MASW test which allows the peat soil investigation in its natural state motivated the investigation of optimum configuration for peat soil condition. The challenges for active MASW investigation on peat soil location includes highly compressible material with very high-water content which causes the seismic energy to be dampened much quicker compared to other type of soil and needs longer time of recording. The highly compressible material of peat soil also causes the source plate to be buried into the ground upon impacted with the source weight (i.e. sledgehammer), resulting in inconsistent impact during stacking [16], [17]. Planting the geophone sensor was also challenging as the low friction and soft material provides lesser grip on the geophone spike risking tilted condition and results in incorrect readings. Therefore, the study focused on investigating the optimum field configuration on peat soil for better data gatherings and more accurate data interpretation.

2. Materials and Methods

The MASW field measurements were carried out at Parit Nipah, Johor in South Peninsular Malaysia. The soil at Parit Nipah is mainly peat soil with soft marine clay as the underneath soil. The study area is situated within the quaternary region which consists of marine and continental deposits such as clay, silt, sand, peat with minor gravel (see Fig. 1). The location was chosen as the peat soil thickness was among the thickest in Peninsular Malaysia. The peat thickness and groundwater table determined in the area were approximately 4 m and 0.5 m depth respectively [18]. The peat soil type was categorised as hemic peat according to the Von Post classification [19]. The area was mainly used for agricultural activities and mostly covered by palm oil and pineapple tree.

The field surveys were conducted using 24 geophones with natural frequency of 4.5 Hz as receivers. The general field arrangement is as shown in Fig. 2. A 7 kg sledgehammer was used as impact sources with rubber plate as the impact absorber. As mentioned by Basri et al. [20] and Taipodia et al. [21], rubber plate provides higher signal to noise ratio particularly at the lower frequencies and minimised the plate penetration during impact. The number of stacking was set to 5 to ensure sufficient energy obtained and the sensor arrangement was fixed with the constant linear arrangement. Four configurations including the receiver spacing (dx), source offset (X_1), geophone frequency and sampling interval were investigated. For the receiver spacing investigation, three survey lines with constant midpoint but different receiver spacing (dx = 0.5, 1.0 and 1.5 m), were tested. The source offset was fixed at a distance half the total spread length (L) (X_1 = L/2). For the source offset distance, 5 configurations (L/0, L/1, L/2, L/3 and L/4) were investigated based on the total spread length. While for the sensor frequency and sampling interval, two types of sensor frequency (4.5 and 28 Hz) and 7 different sampling intervals (25, 50, 100, 250, 500, 1000 and 2000 μs) correspondingly were investigated. The number of samples were adjusted according to the sampling interval to ensure optimal total recording time.

3. Results and Discussion

3.1 Receiver Spacing

The receiver spacing is the distance between two consecutive geophone sensors. The receiver spacing distance directly influenced the generated frequency range (wavelengths), which governs the deepest depth of investigation (Z_{max}) and the shallowest measurable depth (Z_{min}). Previously, the depth of penetration used is approximately equal to the wavelength (λ) which is normally assumed equal to total spread length (λ = L) [22]. However, the widely accepted equation to calculate the depth of penetration is, $Z_{max} = \lambda_{max}/2$ [8,23–25]. The separation between different modes of surface waves are also influenced by the total spread length (L) which is governed by the receiver spacing distance [12]. Three receiver spacing distance were compared which includes 0.5, 1.0 and 1.5 m. The dispersion images obtained using all receiver spacing were as shown in Fig. 3(a) to Fig. 3(c). The dispersion images obtained clearly shows the mapped fundamental and the higher modes dispersion curves. The better quality of dispersion image was observed when using 1.0 m receiver spacing (Fig. 3(b)), which is certainly due to high signal to noise ratio shown by high amplitude dispersion curve compared to 0.5 m (Fig. 3(a)) and 1.5 m (Fig. 3(c)) receiver spacing. When using 1.0 m receiver spacing, the bandwidth obtained was narrow and the separation of different modes were clear, which ease the plotting of fundamental-mode dispersion curve. Much wider frequency range was obtained using 0.5 m receiver spacing, but the domination of higher modes was significant which causes difficulties in separating the different modes. The bandwidth obtained also was wider, causing difficulties to determine the peak amplitude for dispersion curve

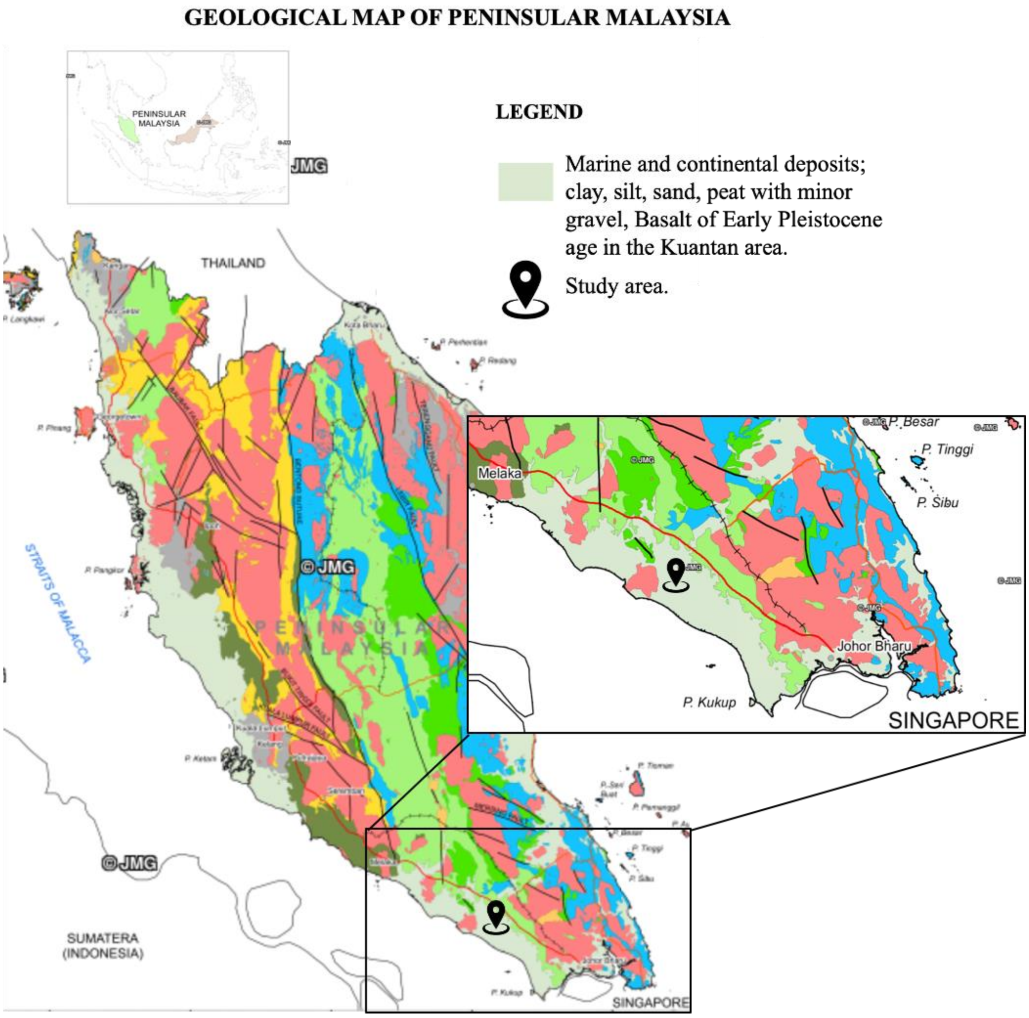


Fig. 1 - Location of MASW field measurements at Parit Nipah in South Peninsular Malaysia

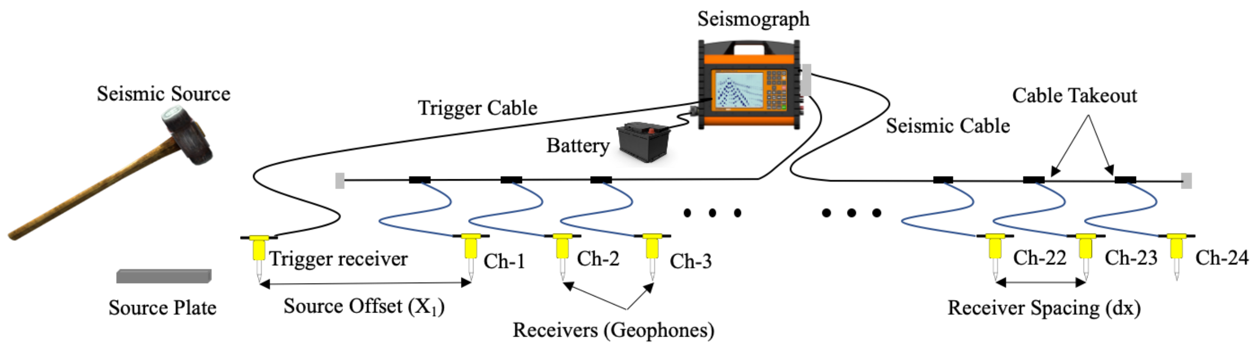
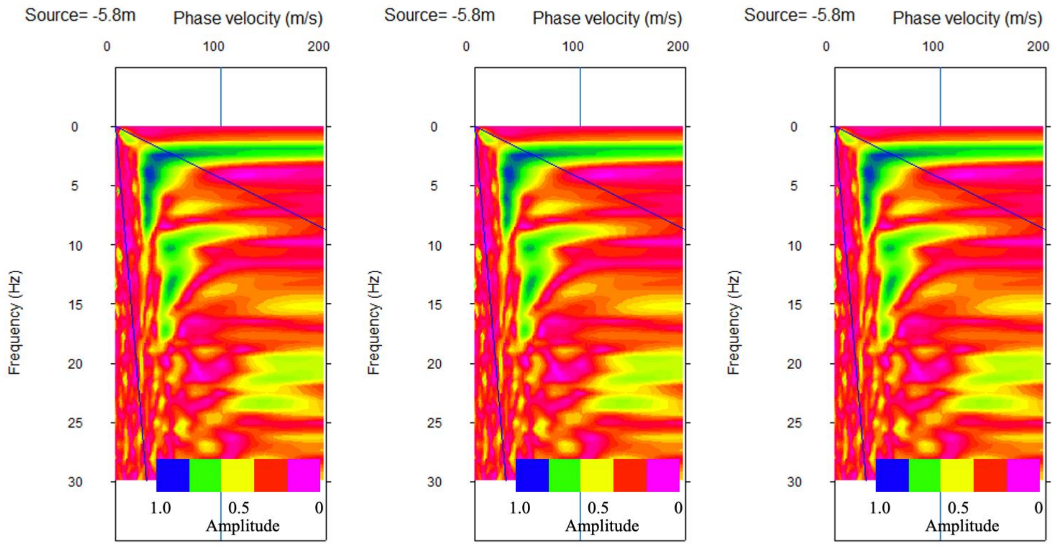


Fig. 2 - General field arrangement for active MASW survey

plotting. For 1.5 m receiver spacing, the signal to noise ratio decreases significantly on the overall spectrum and the higher frequencies were scattered. As mentioned by Bullen [26] and Olafsdottir et al. [27], the high-frequency (short wavelength) tend to attenuate rapidly over distance and the continuity was negatively affected. This behaviour also was likely due to the rapid dissipation of seismic energy on the peat soil as the higher frequencies were related to the shallow part where the soil layer was peat soil. The large total spread length also results in significant drop on the overall signal to noise ratio as longer distance travelled leads to rapid attenuation of active energy crossing the array and negatively affect the continuity of the higher frequencies [27,28]. Despite the low signal to noise ratio, slight increase in the lowest frequency obtained was observed providing deeper depth of penetration. However, the higher frequencies obtained were very low which will reflect on lesser details on the shallow part of the profile obtained. Therefore, longer spread length provides better resolution dispersion image, deeper depth penetration and clear separation between different modes. But, an increase in the total spread length by further increasing the receiver spacing (≥1.5m) will result in lower resolution dispersion image. Thus, the increase in the total spread length must be accompanied by increasing the number of receivers to ensure high resolution dispersion image and deeper depth of investigation [11], [28].

The frequency range obtained for 0.5, 1.0 and 1.5 m receiver spacing were approximately between 3 to 23 Hz, 2 to 14 Hz, and 2 to 10 Hz respectively. The frequency range obtained was wider and larger number of high frequencies were recorded when using smaller receiver spacing, providing extensive details on the shallow part of the V_s profile. As the receiver spacing increases the higher frequencies drop significantly causing lesser details which leads to data interpolation and extrapolation during data processing. However, the lowest frequency (longest wavelength) recorded increases as the receiver spacing increase which contributes to deeper depth of penetration. 1.0 m receiver spacing was recommended for peat soil investigation as it provides sufficient lower frequencies and minimum loss of higher frequencies. The resolution of the overall spectrum was also high with clear separation of different modes and narrower bandwidth which eased the extraction of the fundamental mode dispersion curve. If deeper depth of investigation was required, adding more receivers to increase the total spread length was recommended to ensure high quality dispersion image obtained rather than further increasing the receiver spacing. The use of longer receiver spacing (≥1.5m) if necessary, must be accompanied with heavier source weight and greater number of stackings to provide sufficient impact energy.



(a) (b) (c)

Fig. 3 - Dispersion images obtained using; (a) dx = 0.5 m; (b) dx = 1.0 m; and (c) dx = 1.5 m

3.2 Source Offset

Fig. 4(a) to Fig. 4(e) shows the dispersion images obtained using 1.0 m receiver spacing with different source offset (X_1) distance. The distance of the source offset determined are based on the total spread length (L). Five configurations were investigated which includes L/0, L/1, L/2, L/3 and L/4. Low quality dispersion images were observed on Fig. 4(a) to Fig. 4(c) and Fig. 4(e), which were certainly due to influence of the near-field and far-field effect. The influence of near-field effect was observed on Fig. 4(a) to Fig. 4(c) where the signal to noise ratio were low especially on the lower frequencies due to the short source offset distance. This could be attributed by the non-planar wave recorded as the lower frequencies (longer wavelength) needs to travel a certain distance before the wave become planar [8]. As for the far-field effect shown in Fig. 4(e), the signal to noise ratio on the overall spectrum was very low. The evident of the domination of higher modes were significant causing difficulties to separate different modes. According to Park et al. [23], Olafsdottir et al. [27], Park and Shawver [29], and Sauvin et al. [8], far-field effect causes contamination of body waves due to attenuation of high frequency which causes interference of higher modes and limits the highest frequency measured. The low signal to noise ratio obtained also could be attributed by the peat soil characteristics as the energy loss was higher on peat soil as longer distance travelled. However, clear separation between different modes was achieved using all source offset distance. High quality dispersion image was obtained when using source offset distance of half the total spread length ($X_1 = L/2$) as shown in Fig. 4(d). High signal to noise ratio was observed on the overall spectrum shown by high amplitude dispersion curve, clear separation between different modes and unbroken higher frequencies. According to Olafsdottir et al. [27], high amplitude and unbroken higher frequencies were obtained with medium length source offset distance. While Park and Carnevale [24], mentioned that the optimum source offset distance is critical to reduce the adverse influence especially from the near-field effect.

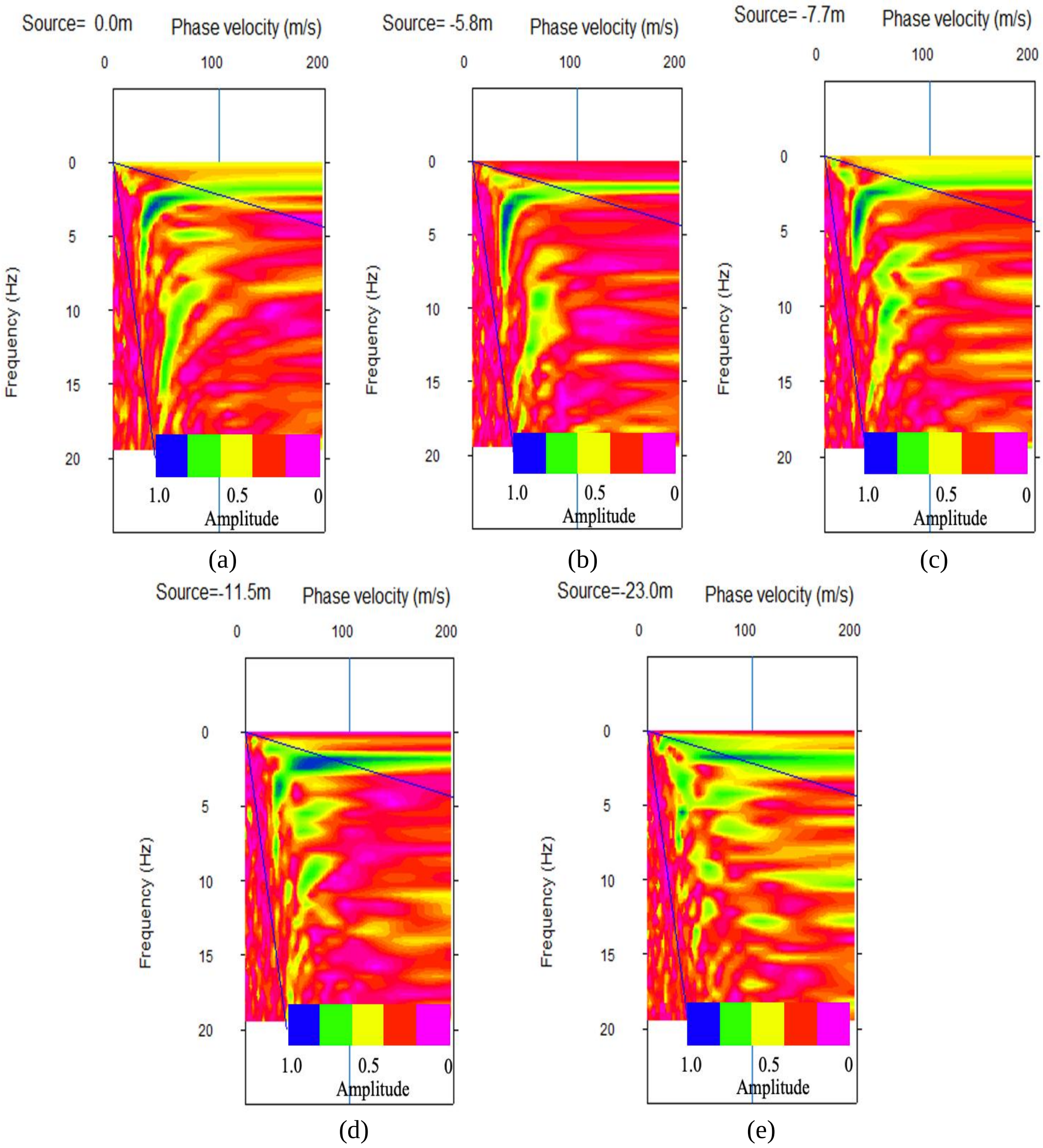
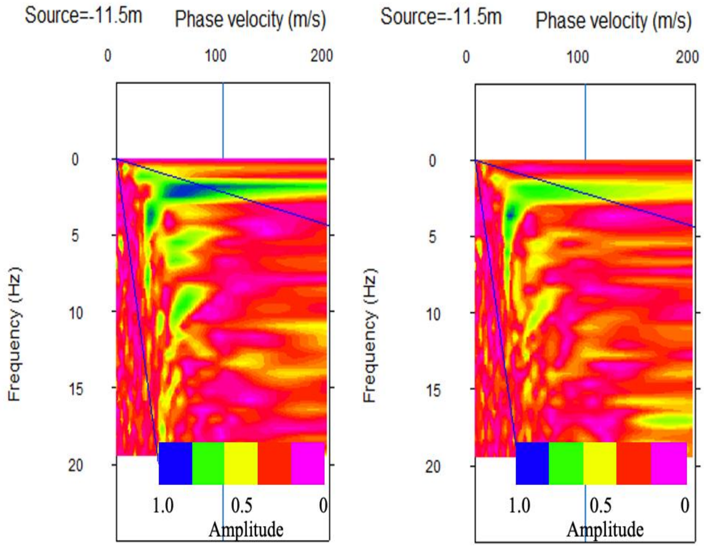


Fig. 4 - Dispersion images obtained using 23 m total spread length with; (a) X_1 = 0 m; (b) X_1 = 5.75 m; (c) X_1 = 7.7 m; X_1 = 11.5 m; and X_1 = 23 m

3.3 Sensor Frequency

The natural sensor frequency determines the range of frequencies recorded by the seismograph during data collection. Lower natural sensor frequency allows lower frequencies to be recorded providing deeper depth of penetration. While, higher natural sensor frequency limits the records of the lower frequencies but in return provide better resolution for the higher frequencies, thus, greater details on the shallow layer part. However, based on the findings, the lowest frequency obtained supress the natural frequency of the sensor used. The 4.5 Hz sensor was able to record high amplitude signal as low as 2 Hz. While, the 28 Hz sensor can record signal approximately up to 3 Hz but with lower amplitude. Similar finding was obtained by Long and Donohue [30] where the lower frequency level was not restricted by their respective natural frequency and they could possibly detect lower frequency signal. The signal to noise ratio was low when using high sensor frequency (28 Hz) especially on the lower frequencies compared to 4.5 Hz.

However, the domination of higher modes was slightly lower when using 28 Hz sensor frequency and the higher frequencies were much clearer.



(a) (b)

Fig. 5 - Dispersion images obtained using; (a) 4.5 Hz; and (b) 28 Hz

3.4 Sampling Interval

The total sampling time is the combination between the sampling interval time and the volume of samples configured on the seismograph. Sufficient recording time is important to ensure complete shot gathers recorded. According to Taipodia et al. [31], the sampling time is site dependant and high sampling frequency is recommended. Fig. 6(a) to Fig. 6(g) shows the shot gathers obtained for all sampling interval available on the equipment for comparisons. Incomplete shot gathers were observed on Fig. 6(a) and Fig. 6(b) where only a part of the secondary wave was recorded due to short sampling time. While for the other sampling time, the secondary wave was able to be recorded completely. The negative effect of incomplete shot gathers recorded can be seen on Fig. 7(a) and Fig. 6(b), where scattered energy bands were observed across the entire spectrum. The lower frequencies suffer the most as it needed longer time to become complete and the short sampling intervals (25 and 50 μs) were unable to provide sufficient sampling time even when the maximum number of samples available were used. The characteristics of peat soil including the high void ratio and low stiffness also causes slower wave travel time causing the needs of longer sampling time. Generally, the stiffer stratum allows faster wave propagation compared to that of softer stratum [31]. As for the other sampling interval where sufficient recording time was achieved, no significant changes in dispersion image resolution was observed. However, short sampling interval coupled with suitable number of samples was recommended as denser data will be obtained which then will minimise the need of data interpolation and extrapolation during data processing.

4. Conclusions

The optimum configuration investigation for active MASW method survey was conducted to optimise the application of the method on peat soil condition. Due the limited presence data on the optimum configuration for peat soil, the comparison made was mostly done with the configurations on soft clay. Based on the results, it is concluded that 1.0 m receiver spacing provides the best dispersion image resolution when investigating on peat soil. Sufficient frequency range for detailed depth profile, high signal to noise ratio, narrow bandwidth and clear separation between different modes were achieved. The optimum source offset distance determined was about half the total spread length (X_1 = L/2) as shorter source offset distance causes near-field effect which deteriorate the lower frequencies fundamental mode. While, longer source offset causes far-field effect as the energy dissipate much quicker on peat soil with distance. The comparison made between 4.5 and 28 Hz natural sensor frequency shows that lower sensor frequency provides higher signal to noise ratio dispersion image particularly at lower frequencies. The lowest frequency recorded also supress the limitation of the natural sensor frequency as lower frequency than the natural frequency was recorded. While, the sampling interval shows no significant influenced on the dispersion image resolution as long sufficient recording time was provided. Overall, the field configuration shows significant influenced on the generated dispersion image. Therefore, extra care must be taken to ensure high quality dispersion image was obtained to prevent underestimation or overestimation of the V_s profile constructed.

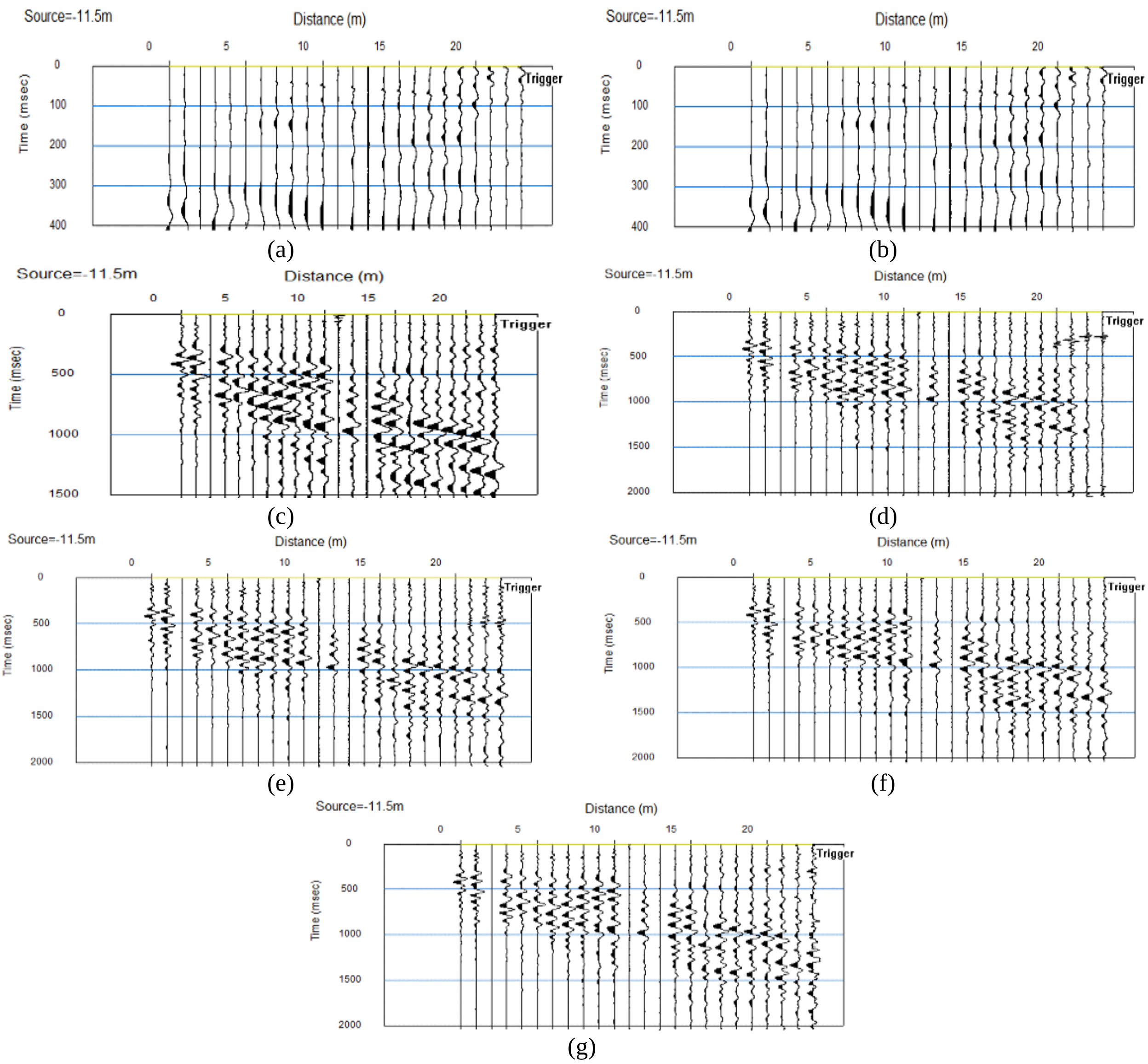


Fig. 6 - Shot gathers obtained using sampling interval of; (a) 25 μs; (b) 50 μs; (c) 100 μs; (d) 200 μs; (e) 500 μs; (f) 1000 μs; and (g) 2000 μs

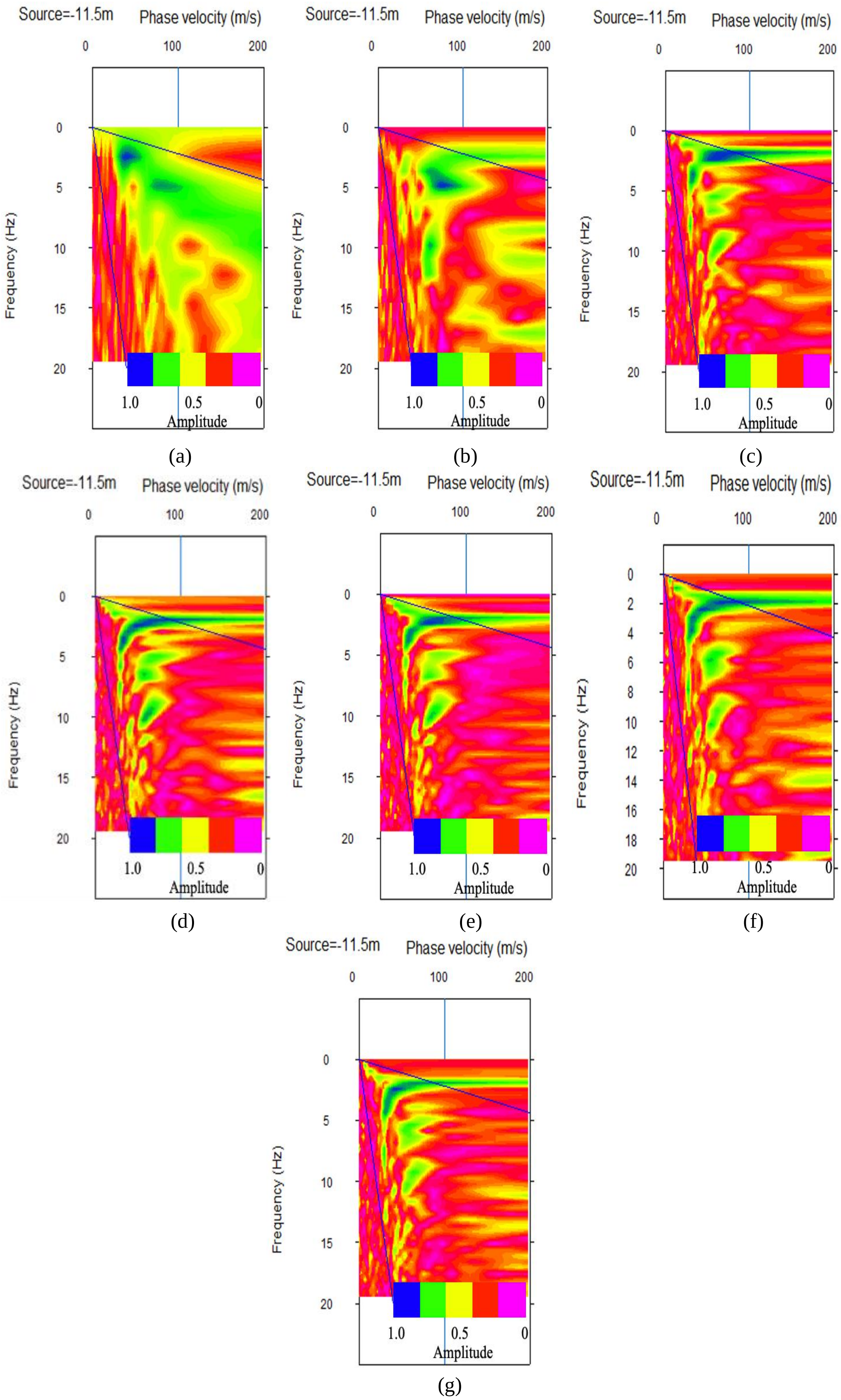


Fig. 7 - Dispersion images obtained using sampling interval of; (a) 25 μs; (b) 50 μs; (c) 100 μs; (d) 200 μs; (e) 500 μs; (f) 1000 μs; and (g) 2000 μs

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