MODAL SEPARATION BEFORE DISPERSION CURVE EXTRACTION BY MASW METHOD

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Abstract

Accurate extraction of dispersion curves is the most critical part with any surface-wave method. Although a multichannel method like Multichannel Analysis of Surface Waves (MASW) method proves most effective for this purpose, there are several acquisition parameters that need to be set properly for the optimal extraction. One of them requires a long range of receiver spread to separate phase velocity of one mode from those of other modes. Sometime, however, this requirement can not be met due to an unacceptable lateral inhomogeneity in the near-surface materials being surveyed and therefore multichannel records are often collected with a relatively short spread length. In this case the interference between the different modes of surface waves can be so severe that neither fundamental nor higher-mode dispersion curve can be extracted with a reliable confidence. In addition to this multimodal effect by surface waves, other types of seismic event such as channel (guided) waves can cause similar harmful effect during the analysis. When this occurs, a simple multichannel processing technique that mutes the interfering wavefields in the offset-time (*x-t*) domain can significantly enhance the resolution of multimodal dispersion curves. This is demonstrated by using both synthetic and real shot gathers.

Introduction

Usually surface wave takes about 70% of the total seismic energy. This wave attenuates with depth and propagates dispersively when there is velocity variation in the media of propagation. Larger wavelengths penetrate greater depths and smaller wavelengths sample the shallow depths. Thus, smaller wavelengths are influenced by the seismic properties (mainly shear wave velocity Vs) of the shallow parts of the media while larger wavelengths are influenced by those of the deeper parts of the media. Because of this phenomenon, when there is velocity variation with depth, different wavelengths will travel with different speed. This is known as dispersion. It is usually estimated by measuring surface wave phase velocities over certain range of frequencies and by constructing a dispersion curve. Moreover, in general surface wave propagates in several modes, which means that the dispersion property may be represented by several curves of different modes. The one that is at the lowest velocity range is known as fundamental mode, and the ones that appear at higher velocity ranges than the previous are known as higher modes (1^{st}, 2^{nd}, etc.).

The multichannel analysis of surface waves MASW method (Park et al., 1999) being extensively investigated at the Kansas Geological Survey analyzes Rayleigh type surface waves to investigate the near surface (<150ft). First, from a shot record it extracts the fundamental mode dispersion curve. Then the extracted dispersion curve is inverted (Xia et al., 1999a) into a vertical section of the shear velocity Vs. Recently, an inversion method applied to multimodal dispersion curves showed a unique advantage one can have with the multimode analysis (Xia, et al., 2000). The multichannel approach to dispersion curve analysis can significantly improve the signal-to-noise ratio (S/N) as well as the abilities of pattern recognition (Park et al., 1998a) that enable the identification of different types of seismic waves from their arrival and attenuation pattern.

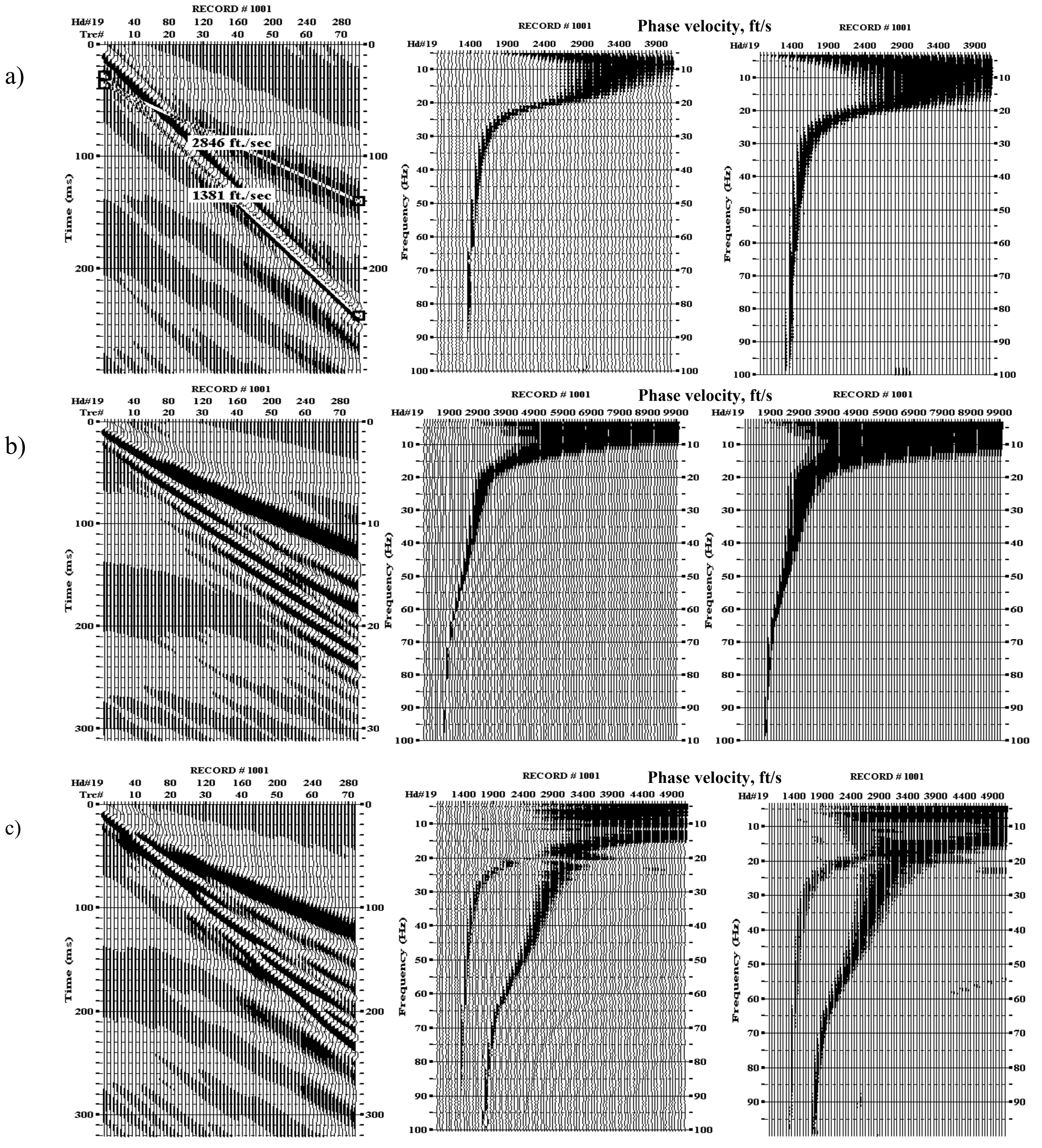

Figure 1. Each row displays a shot record and two dispersion curve images obtained by using two different dispersion curve extraction techniques. a) Analysis only of the fundamental mode model record. b) Analysis only of the 1st higher mode model record. c) Analysis of joint fundamental and 1st higher modes model record.

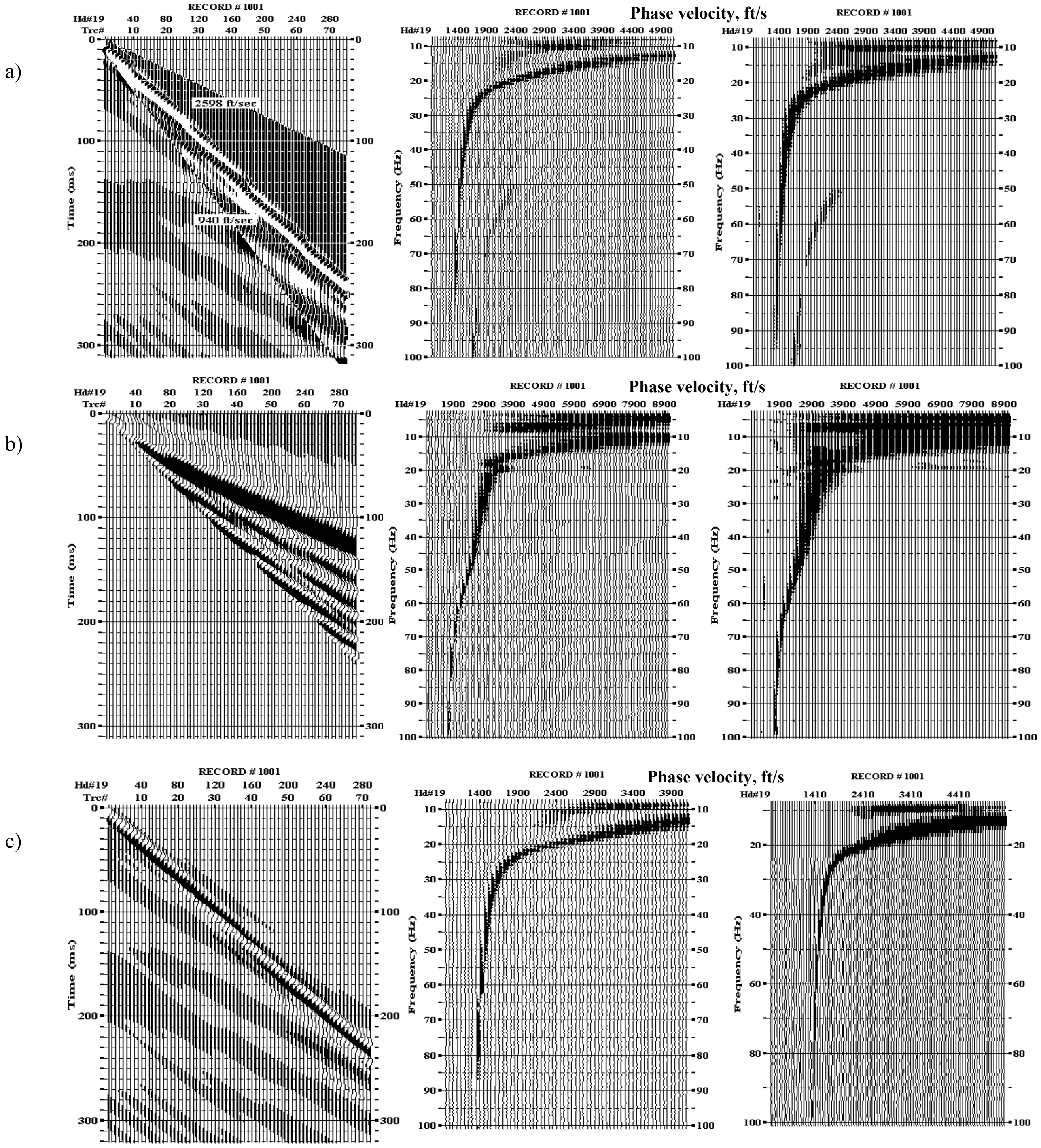

Figure 2. Each row displays a shot record and two dispersion curve images obtained by using two different dispersion curve extraction techniques. a) Analysis only of the fundamental mode model after removing the 1st higher mode from the joint fundamental and 1st higher modes modeled record. b) Analysis only of the 1st higher mode model after removing the fundamental mode from the joint fundamental and 1st higher modes modeled record. c) Analysis only of the fundamental mode after removing erroneously recognized higher mode from the fundamental mode modeled record.

The MASW method was applied to many sites for solving various problems such as: Seismic characterization of pavements (Park et al., 2001a; Ryden et al., 2001), study Poisson's ratio (Ivanov et al., 2000a), seismic investigation of sea-bottom sediments (Park et al., 2000b; Ivanov et al., 2000b), mapping bedrock surface (Miller et al., 1999a), detecting dissolution features (Miller et al., 1999b), generation of S-wave velocity profiles (Xia, et al., 1999b).

Accurate dispersion curve extraction is very important element of the MASW method because any error in the dispersion curve would cause inversion to produce an inaccurate vertical Vs section. However, often other types of the seismic wave field such as the direct wave, refracted waves, guided waves, the air wave as well as higher modes of the surface wave may act as noise and interfere with extraction of accurate dispersion curves. MASW can handle such types of noise only if several acquisition parameters are met. The most important parameter is large receiver spread. Often such requirement may harm the horizontal resolution of the method and be unacceptable.

The goal of this paper is to analyze a shot record and show the importance of removing those parts of the wave field that may act as noise on the process of extracting a dispersion curve. We use simple mute process for separating different wave fields.

Method

In our first step we analyze three different synthetic shot gathers having fundamental mode, 1st higher mode and both. We study how we can remove the negative influence of the 1st higher mode on the process of extraction of fundamental mode of the surface wave. In our second step we apply the improvement technique to real data.

We use two dispersion curve extraction techniques (Park et al., 2000a). One has better resolution capabilities, the other has better pattern recognition properties. In our figures we display both types of dispersion curves for better imaging of the dispersion curve phenomenon.

Figure 1a shows how a shot record and a dispersion curve would look like if the surface wave consists of the fundamental mode dispersion only, shown on Figure 3. Figure 1b shows how a shot record and a dispersion curve would look like if the surface wave consists of only of 1st higher mode dispersion (Figure 3). Figure 1c shows how a shot record and a dispersion curve would look like if the surface wave consists of both fundamental and 1st higher mode dispersions. We can see how the two dispersion curve images are well separated above 20Hz and how they interfere below 20Hz. By muting the joint modes shot record (Figure 1c) we try to separate the two modes into two separate shot records containing the fundamental mode and higher mode only (Figure 2a and Figure 2b). We analyze the corresponding dispersion curves and compare them with the dispersion curves of the single mode surface wave on Figure 1a and Figure 1b.

This modeling example shows that we could achieve separation between the fundamental and higher modes and managed to pick dispersion curve values in the range 17-20 Hz. This is shown as curve FUND1ST Bellow 0(1001).DC on Figure 3. Nevertheless, we couldn't pick fundamental mode in the range 9-16Hz. This is due to the fact that this part of the fundamental mode travels with velocity in the range of 3000ft/s (Figure 1) and appears on the shot record at the same place (in terms of traces and time) as the higher mode. As a result we muted out not only the higher mode but as well as part of the fundamental mode. Such closeness between the fundamental and higher mode velocities is uncommon but not impossible. We picked such case for our theoretical example to show the possibility of muting parts of the fundamental mode as we mute the higher mode. However, even in such extreme closeness, we managed to improve the fundamental mode picking by muting the higher mode.

The possibility of separation by muting is stipulated by the higher velocities of the higher modes. Higher mode energy would appear with smaller slopes than the fundamental mode.

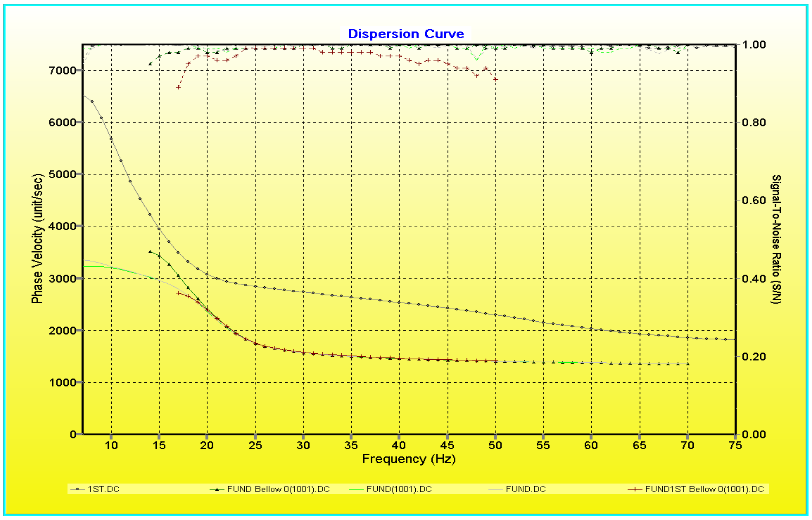

Figure 3. Fundamental mode (FUND.DC) and 1st higher mode (1ST.DC) dispersion curves used for modeling, fundamental mode (FUND(1001).DC) picked by MASW by analyzing the fundamental mode record from Figure 1a, (FUND Bellow 0(1001).DC) picked by MASW after removing the top higher velocity event from the record modeled by the fundamental mode only and fundamental mode (FUND1ST Bellow 0(1001).DC) picked by MASW after removing the top higher velocity event from the record modeled by both fundamental and higher modes.

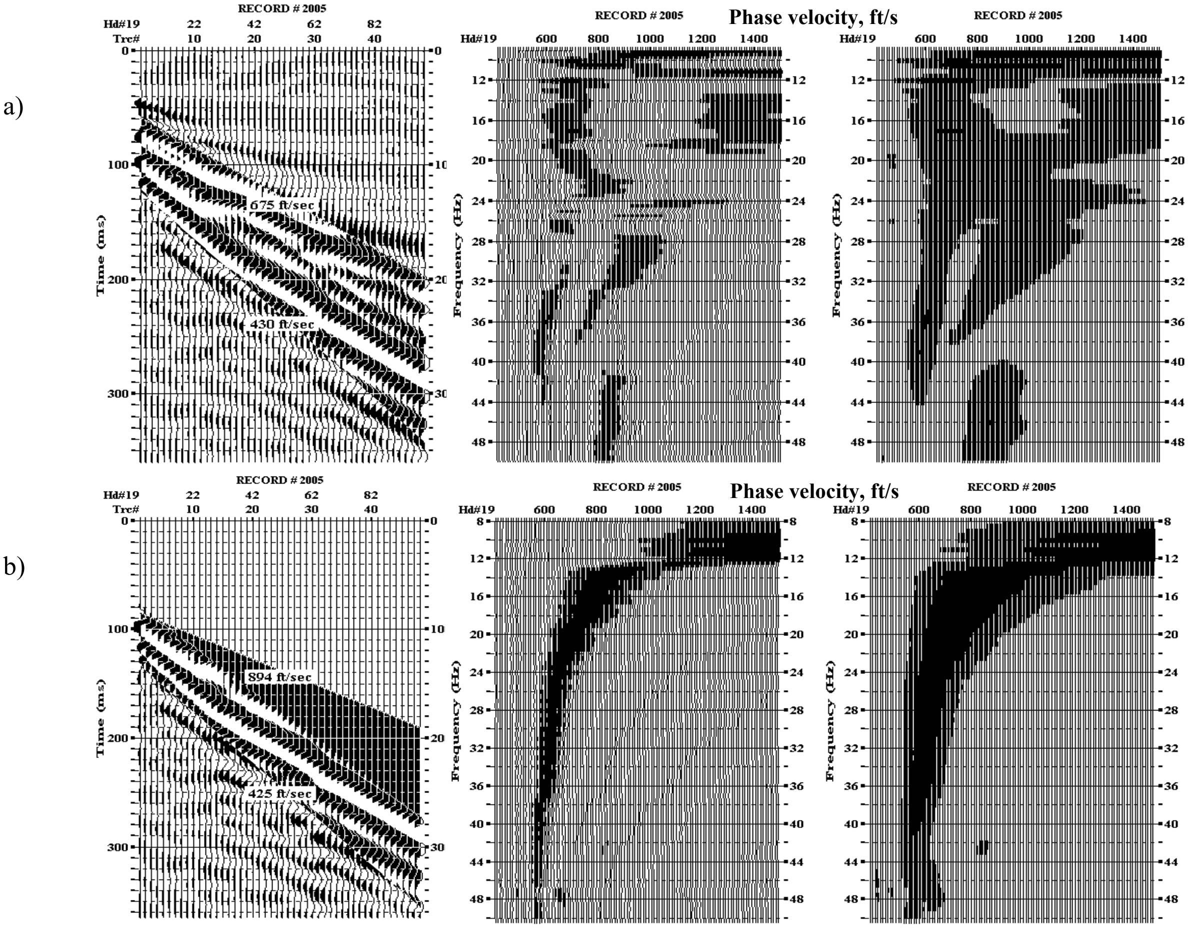

Figure 4. Garland data, Line 2. a) Shot containing all waves. B) Shot after muting wave considered as noise.

Data Examples

Two seismic lines were collected at Garland, Michigan, using Geometrics StrataView seismograph, 48 channels and 4.5 Hz geophones. Data for Lines 1 and 2 were acquired along the identical line with different geophone placements.

Geophone spacing for Line 2 was 2 ft, and the shot offset was 4 ft. After analyzing a shot record we couldn't extract a fundamental mode dispersion curve. One can observe how unclear the dispersion curve image is on Figure 4a. After muting the wave field that did not appear as fundamental mode we obtained a very clear image of the dispersion curve (Figure 4b). We show on Figure 5a the muted part of the wave field that we consider as noise that harmed our dispersion curve picking on Figure 4a. In this data set we could go further and separate the higher mode region (Figure 5b) from the guided wave region (Figure 5c). This wavefield separation technique may become useful for further analysis of the wave field such as multimode inversion (Xia et al., 2000) or inversion of guided waves (Roth and Holliger, 1999).

MASW is capable of separating fundamental mode from other noise on its own if the receiver spread is large enough (Park et al., 2001b). The geophone spacing for Line 1 was 4 ft, and the shot offset was 4 ft. The field acquisition parameters were appropriate for MASW to be able to extract the fundamental mode dispersion curve without any help (Figure 6a). This dispersion curve is identical to the dispersion curve obtained after muting the noise waves from the half spread shot of line2 (Figure 4b). Still, by applying the wave field separation by muting we managed to achieve improvement of the fundamental mode dispersion curve picking in the range of 13-16Hz (Figure 6b). These two dispersion curves can be compared better on Figure 7.

By comparing Figures 5 and 8 one can observe how larger receiver spread improved extraction of non-fundamental type of dispersion curves such as higher modes (Figure 8b) and guided wave (Figure 8c).

Figure 9 compares fundamental mode dispersion curves before and after muting.

Conclusions

The possibility of separation by muting is stipulated by the higher velocities of the higher modes. Higher mode energy would appear with smaller slopes than the fundamental mode.

By analyzing multichannel record and applying multichannel processing technique such as muting we can significantly improve the dispersion curve picking using MASW.

This wave field separation muting technique is valuable because it provides us with a general tool for improvement of dispersion curve picking. Moreover, it allows us to acquire data with smaller spreads and thus significantly increase the horizontal resolution. For example a small spread survey can be designed with a few larger spread shots for quality control. This would ensure that the muting of the smaller spread data is appropriate and dispersion curve processing results with the same dispersion curves as with the larger offset data.

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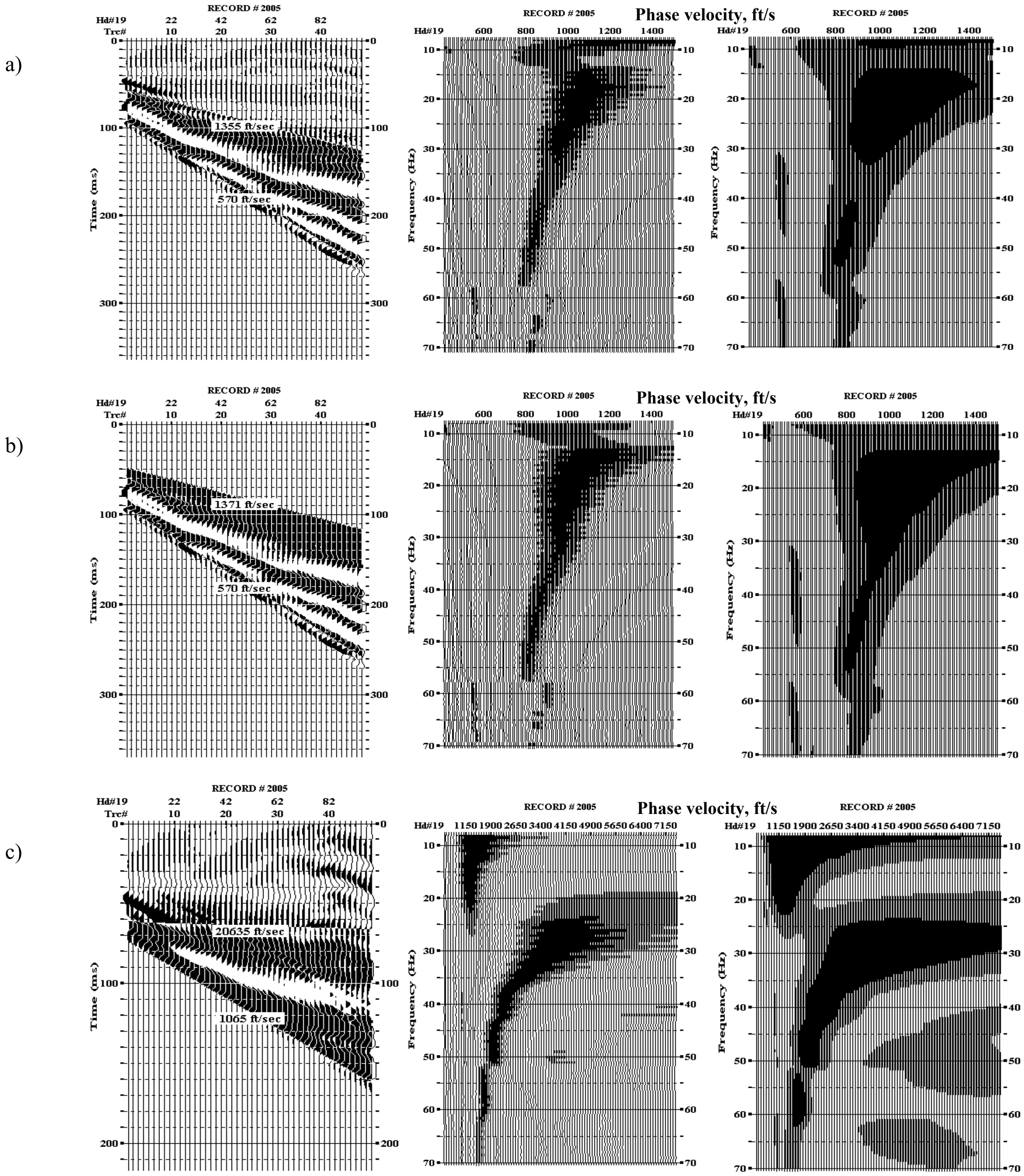

Figure 5. Garland data, Line 2, a) higher modes and guided wave analysis. b) higher modes only analysis. c) guided wave analysis (note different scale for the phase velocity).

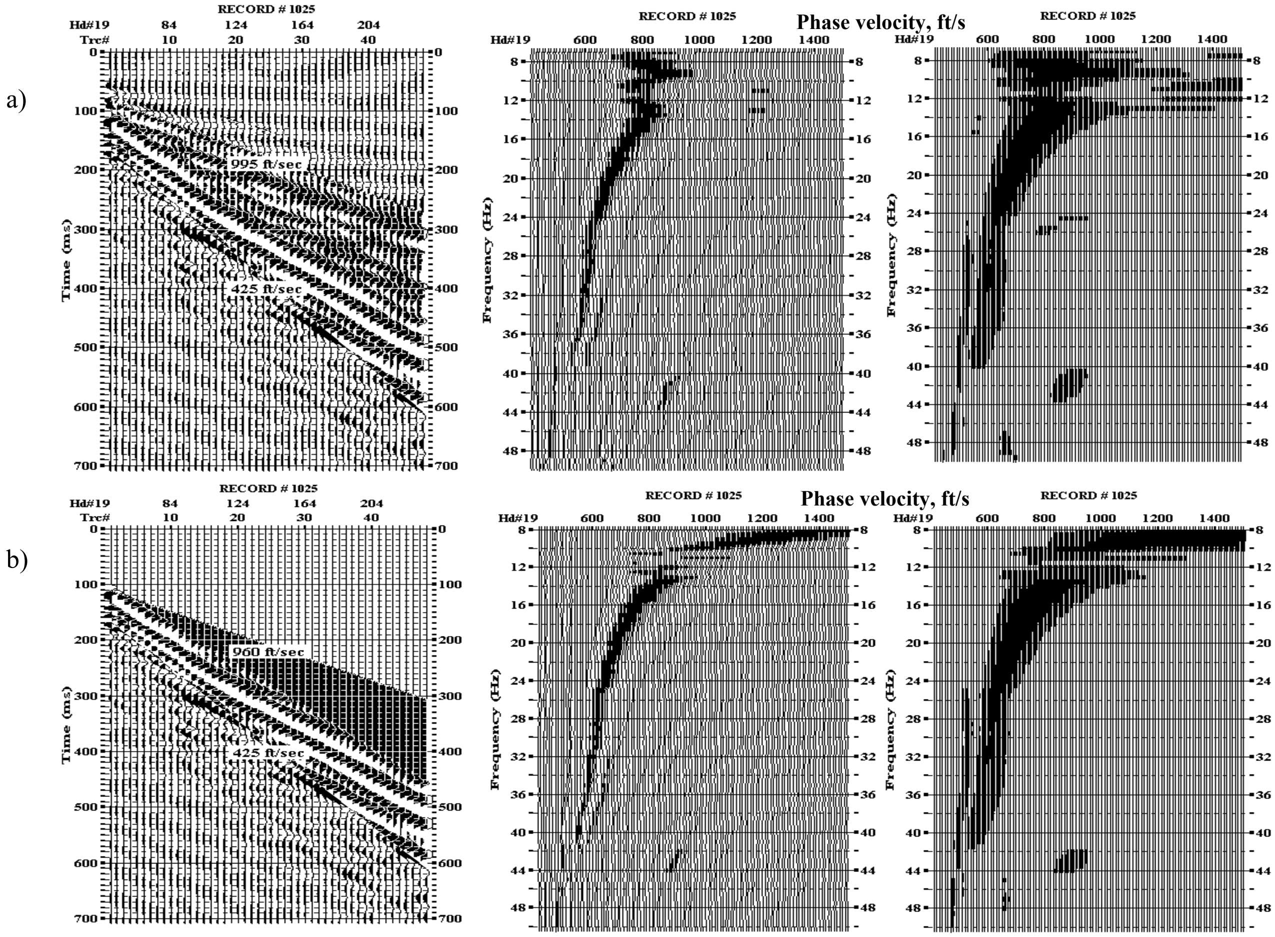

Figure 6 . Garland data, Line 1. a) Shot containing all waves. b) Shot after muting waves considered as noise.

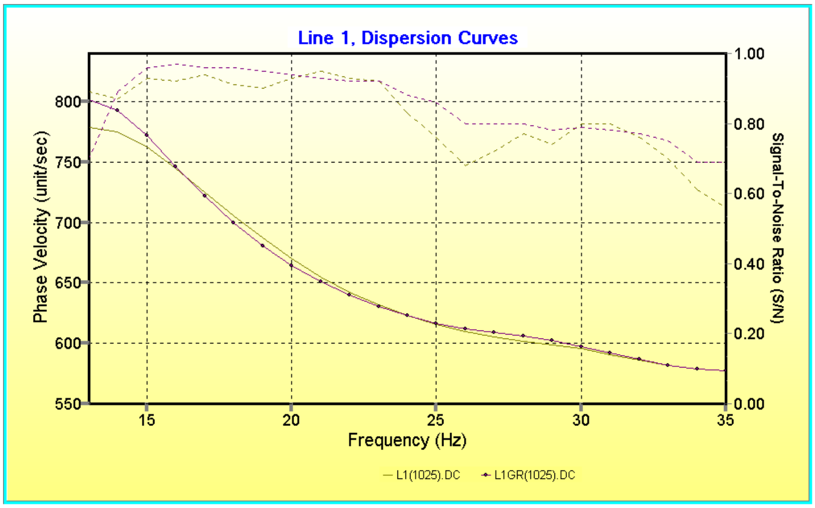

Figure 7. Garland data, Line 1. Dispersion curves picked before (L1(1025).DC) and after muting (L1GR(1025).DC) waves considered as noise.

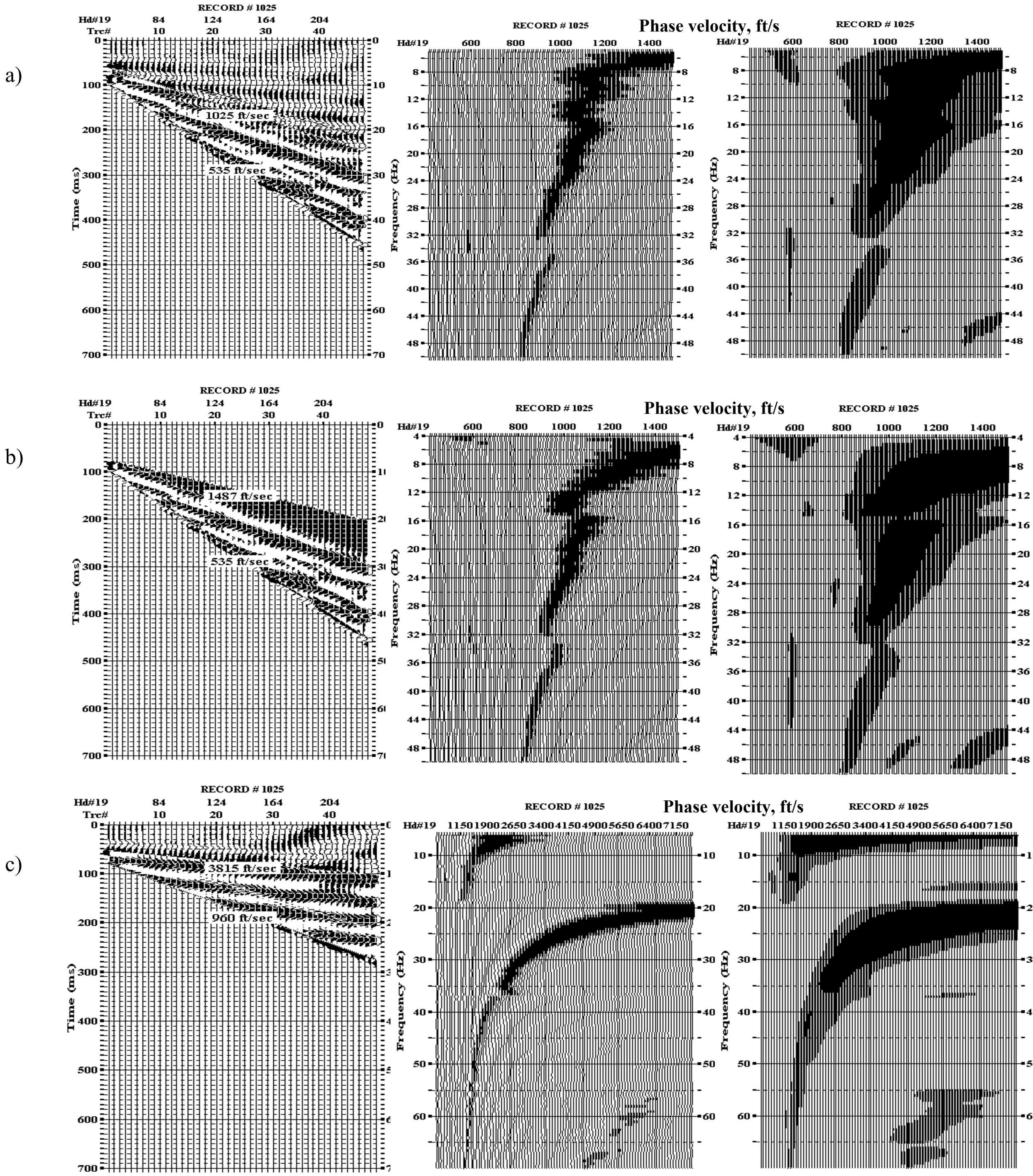

Figure 8. Garland data, Line 1, a) higher modes and guided wave analysis. b) higher modes only analysis. c) guided wave analysis (note different scale for the phase velocity).

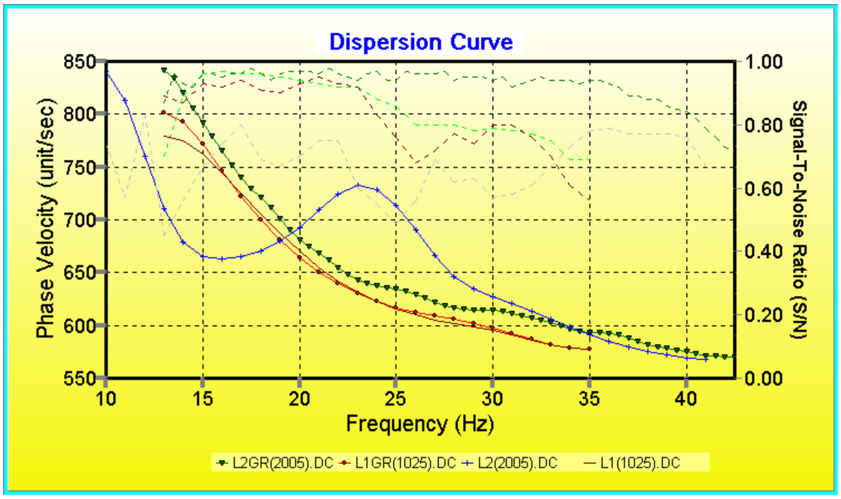

Figure 9. Garland data. Dispersion curves picked before (L1(1025).DC of line 1, L2(2005).DC of line 2) and after muting (L1GR(1025).DC of line 1, L2GR(2005).DC of line 2) waves considered as noise.

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