Feasibility study of near-surface dispersion imaging using passive seismic data

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SUMMARY

Multichannel Analysis of Surface Waves is a seismic technique used to define the near-surface structures and rock properties. It has been commonly used for both geotechnical engineering as well as seismic exploration purposes with active sources. It can also provide information about regolith heterogeneity that is of relevance to reflection seismic data processing. However active surface wave investigations are not always possible due to site restrictions and environmental constraints. In this research, we studied the feasibility of passive seismic for the analysis of surface waves caused by different type of ambient noise and ground motion. The example presented comes from a data set collected over a hard-rock environment. We showed that the achieved results from passive data have a considerable correlation with the results from active data of the same acquisition survey.

Key words: Dispersion imaging, surface waves, near-surface, passive seismic data.

INTRODUCTION

Multichannel Analysis of Surface Waves (MASW) is a seismic method that uses information carried by surface waves to define near-surface structures and rock properties. The method is constructed based on the fact that longer wavelength surface waves probe deeper depths of subsurface formations. Therefore, lower frequencies of the seismic surface waves penetrate to the deeper layers. Using the dispersion of the surface waves with depth, it is possible to estimate the near surface S-wave velocity profile, which describe a subsurface structure in terms of rock properties. The depth of investigation usually does not exceed the first few meters (up to 15m) for a standard 10 Hz geophones. The primary use of MASW is for geotechnical engineering purposes. The profile of the shear velocity provides useful information regarding the near-surface heterogeneities that are of interest to reflection data processing.

Irregular slow velocity distribution caused by near-surface overburden (regolith) is one of the common challenges in the processing of seismic data collected over hard-rock environment (Urosevic and Juhlin, 2007). Such regolith can cause complex wave propagation that is difficult to deal with using seismic reflection methods (Ung et al., 2016). That is why a good estimate of these near surface properties is important and MASW can assist in this task.

MASW has commonly been employed using active seismic surveys with several applications within the last few decades; however, use of active seismic surveys can be problematic and expensive in mine sites. In this paper, we study the feasibility of MASW using passive seismic data using a data set collected over hard-rock environment. To do so, we construct dispersion images using the technique introduced by Park et al. (1999), and invert the S-wave velocities using Occam's inversion (Constable S.C. et al., 1987). The final results from passive seismic data are compared with the results from active seismic data that were collected through the same survey. This can have an impact on the future acquisition strategy and design of MASW surveys.

METHODOLOGY

Application of MASW undertakes the following steps:

- Registration of surface waves generated by various sources
- Dispersion analysis and building dispersion images (Park et al., 1999)
- Inversion of S-velocity profiles by Occam's inversion (Constable S.C. et al., 1987)

In the above steps, vertical components of the records are used to construct the dispersion images. The S-wave velocity profile estimated by MASW is tied to the midpoint of the two-dimensional (2D) receiver profiles. The ultimate result of S-wave velocity model building is achieved by the interpolation of the 1-dimmentional (1D) inverted velocities from the 2D profiles.

FIELD DATA EXAMPLE

In this example we study the feasibility of MASW using passive seismic data collected over hard-rock environment. The data set includes several records with the length of 1 minute. The sampling interval and geophone spacing were 1ms and 3m, respectively. The survey has an orthogonal design with seven inlines. To be able to evaluate the MASW results from passive data, a few number of shots were deliberately triggered by a weight-drop active source. Herein, we use only one of the several records. Figure 1a shows a passive

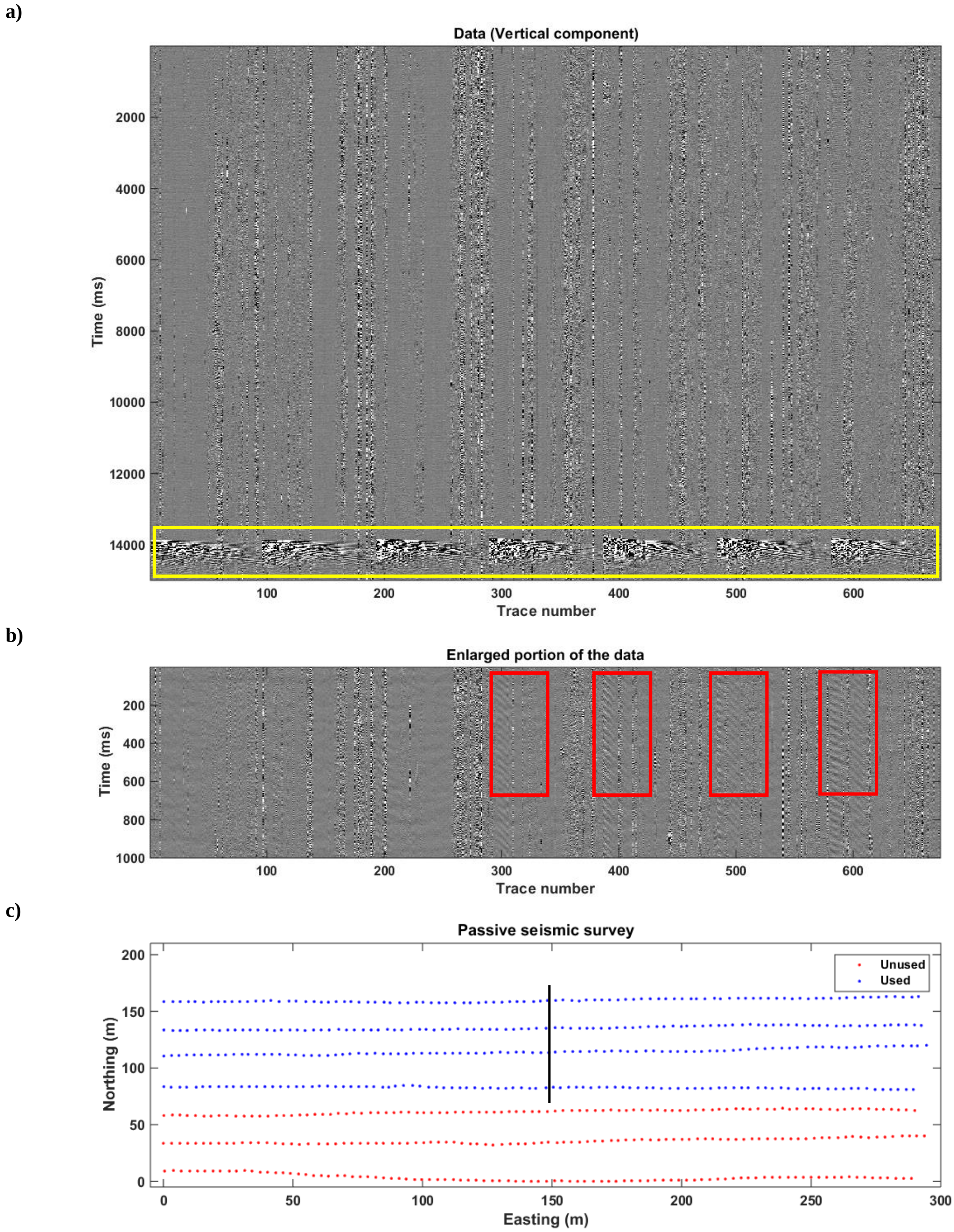

Figure 1: a) Passive seismic record with an active shot shown by the yellow box, b) an enlarged portion of the passive data with showing the surface waves with red boxes, and c) the orthogonal passive seismic survey showing the 2D profiles/inlines used for MASW by the blue dots. The black line shows the location of the final inverted velocity model through MASW.

seismic record and an active shot within the passive record shown by the yellow box. Figure 1b shows an enlarged portion of the passive data indicating the presence of surface waves by the red boxes. It is observed that the surface waves are not pronounced through the whole record. We only use the 2D lines of which have stronger surface waves with higher signal-to-noise ratio (S/N). Figure 1c shows the orthogonal passive seismic survey with the indication of the 2D profiles used for MASW by blue dots. We first analysed the active seismic data. In order to have higher S/N for the analysis of the active seismic data and to keep the contribution of the passive seismic data minimum, the active portions were cropped through the four 2D profiles with the time length of 1000ms. Figure 2a shows one of the inlines used for dispersion imaging using the active survey. Then, we calculated the dispersion spectrum of the data (Figure 2b). The highest amplitudes are manually picked within the dispersion image or S-velocity-frequency spectrum. The picked values are indicated by the black dots/lines in the spectrum (Figure 2b). Finally, S-wave velocity inversion was done using estimated dispersion curve. The corresponding inverted S-velocity is shown in Figure 2c. As mentioned in the methodology section, the inverted S-wave velocities correspond to the middle of the 2D profiles.

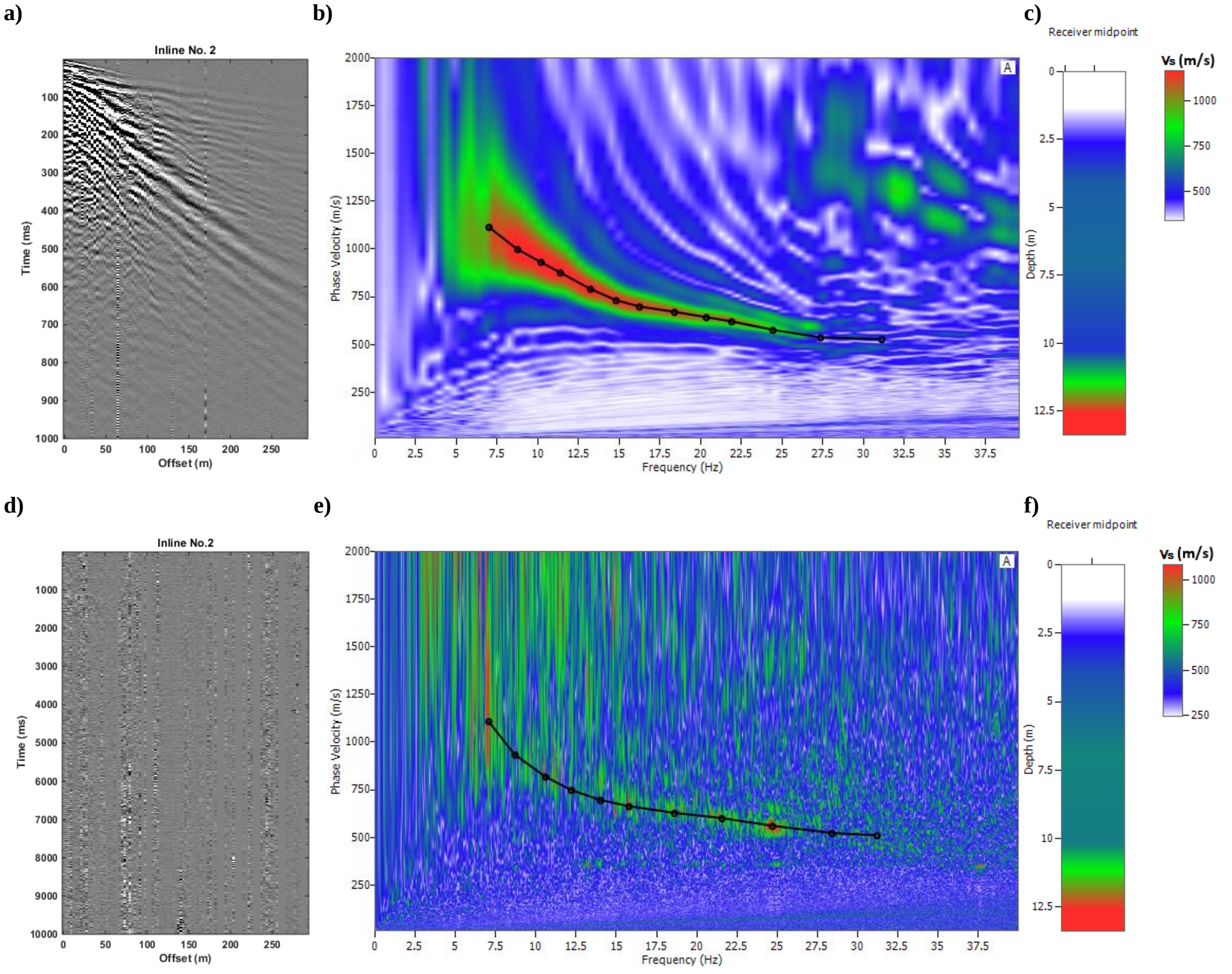

Figure 2: a) Active seismic data separated from pure passive data of inline number 2, the corresponding b) dispersion spectrum and c) inverted S-wave velocity, d) the passive seismic record of the same profile (inline number 2), the corresponding e) dispersion spectrum and f) inverted S-wave velocity. Black dots/lines indicated the manually picked amplitudes through the dispersion spectra.

The same procedure was implemented to the passive data of the same profile/inline. We used 10000ms of the passive seismic data for MASW analysis, shown in Figure 2d. To increase the resolution of the desired outcomes, a trace muting was applied to kill the bad traces within the passive seismic data. It is worth mentioning that since the initial frequency components of the recorded data are important in dispersion imaging, no filtering was applied to the data. The only processing steps applied to the passive data were DC removals and trace muting. Offset is one of the main inputs for the estimation of dispersion curves. Although offset may not be defined for passive seismic imaging, we used relative offset between the receivers for each one of the 2D profiles to be able to calculate the curves. For each inline, offsets were calculated from the beginning of the line from west to east. To investigate the final results in this feasibility study, we used the same defined offsets for both active and passive data. Figures 2e-2f show the dispersion curve and the corresponding inverted S-velocity for the passive seismic profile shown in Figure 2d, respectively. Comparison of the results show a considerable correlation between the inverted S-wave velocity from active and passive data (Figures 2c and 2f).

We repeated the same processing workflow for the other inlines used in this work. To have a better comparison between the achieved results from all the 2D profiles of the active and passive data, we interpolated the inverted 1D S-velocities along the line passing through the midpoints of each 2D profile. The interpolation line is indicated by a black line within the survey in Figure 1c. Figures 3a and 3b show the inverted and interpolated S-wave velocity fields along the black line, respectively. It is observed that there is a considerable similarity between the inverted S-wave velocity fields from active and passive seismic data.

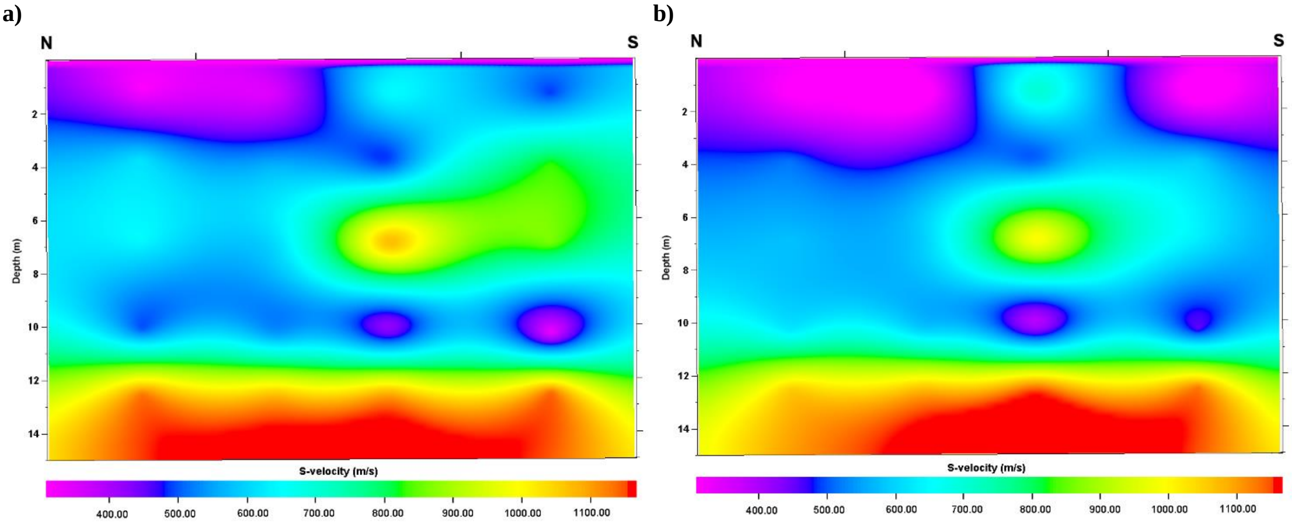

Figure 3: The inverted and interpolated S-wave velocity fields from a) active, and b) passive seismic data along the line indicated by the black line in Figure 1c.

CONCLUSIONS

Multichannel Analysis of Surface Waves is a useful seismic technique to define the near-surface structures and rock properties. Such technique relies on the frequency variation of surface shear-waves with depth. It has been implemented using active seismic surveys for seismic/geotechnical engineering as well as seismic data processing by providing useful information of statics. Such analysis can be very useful for the processing of the seismic data collected over hard-rock environment. In this research, we studied the possibility of passive seismic MASW using a data set collected from hard-rock environment. The obtained results from passive data have a good correlation with the results from active data that were collected from the same acquisition survey. We assumed that the source of the generated surface waves was at the beginning of each 2D passive profile. We also assumed that the orientation of wave propagation is along the east-west direction. The assumptions might not be necessarily correct; however, since the dispersion imaging results from the active and passive data were obtained based on the same assumptions, they are valid for comparison in this feasibility study. More complete and accurate results include few more steps. As a future of this research, it is possible to employ all three components of the recorded data to find the orientation of wave propagation. It is also possible to estimate the location of the passive seismic source using the existing techniques used for earthquake and microseismic monitoring.

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