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Multichannel analysis of surface wave method with the autojuggie

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Abstract

The shear (S)-wave velocity of near-surface materials and its effect on seismic-wave propagation are of fundamental interest in many engineering, environmental, and groundwater studies. The multichannel analysis of surface wave (MASW) method provides a robust, efficient, and accurate tool to observe near-surface S-wave velocity. A recently developed device used to place large numbers of closely spaced geophones simultaneously and automatically (the 'autojuggie') is shown here to be applicable to the collection of MASW data. In order to demonstrate the use of the autojuggie in the MASW method, we compared high-frequency surface-wave data acquired from conventionally planted geophones (control line) to data collected in parallel with the automatically planted geophones attached to steel bars (test line). The results demonstrate that the autojuggie can be applied in the MASW method. Implementation of the autojuggie in very shallow MASW surveys could drastically reduce the time required and costs incurred in such surveys.

Keywords: Surface waves; Autojuggie; Shear-wave velocity; Multichannel analysis of surface waves

1. Introduction

The shear (S)-wave velocity of near-surface materials (soil, rocks, pavement) and its effect on seismic-wave propagation are of fundamental interest in many groundwater, engineering, and environmental studies. Rayleigh waves are surface waves that travel along a 'free' surface, such as the earth–air interface. They are usually characterized by relatively low velocity, low frequency, and high amplitude [1]. For a given mode, longer wavelength surface waves will penetrate more deeply into the earth than shorter wavelengths, generally will exhibit greater phase velocities, and are more sensitive to the elastic properties of the deeper layers [2]. On the other hand, short-wavelength surface waves are more sensitive to and provide potentially better resolution of the physical properties of the shallowest surface layers. This phase velocity and frequency relationship is responsible for the dispersive nature of surface waves. Because the S-wave velocity is the dominant property of the fundamental mode of Rayleigh wave dispersion data, S-wave velocities can be quickly estimated from surface-wave data [3].

The multichannel analysis of surface wave (MASW) method [3–5] is a relatively new technique. This technique consists of (1) a portable, repeatable, seismic source with sufficient energy to provide broadband (~2 to ~100 Hz) Rayleigh waves; (2) a robust, flexible, user friendly, and accurate set of algorithms organized in a straightforward data processing sequence designed to extract and analyze 1D Rayleigh wave dispersion curves; (3) stable and efficient algorithms incorporating the minimum number of assumptions necessary to obtain 1D near-surface S-wave velocity profiles which are iteratively inverted using the generalized linear inversion (GLI) method [3,6]; and (4) construction of the 2D S-wave velocity field. Successful MASW case-history reports include Miller et al. [4] and Xia et al. [7].

The autojuggie is designed to plant several dozen geophones automatically in a few seconds [8] using hydraulically powered mechanical systems. Comparisons between the normally planted geophones with common midpoint (CMP) and with multicomponent techniques using the autojuggie were discussed in Spikes et al. [9] and Ralston et al. [10], respectively. Their results showed that

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planting many closely spaced geophones simultaneously and automatically could drastically reduce the costs and the time in shallow seismic surveys. In addition, little intergeophone interference that could be attributed to the presence of board was found in an experimental research work [11]. Their studies also showed that data acquired by the autojuggie can produce results equivalent to those obtained by conventional methods as long as the necessary processing is applied.

To analyze the feasibility of using the autojuggie in high-frequency surface-wave surveys, we acquired data simultaneously with the conventionally planted geophones (control line) and the auto-planted geophones on bars with the autojuggie (test line). Two-dimensional S-wave velocity fields along both lines were generated for subsequent comparison.

The reason for examining high-frequency surface waves is that high-frequency geophones are often a necessary part of shallow-seismic reflection surveys, and we wanted to determine whether high-frequency MASW survey data could be extracted from a typical shallow reflection survey.

2. Geological setting

Data along the control and the test line were collected at the top of a dam across the street from the Kansas Geological Survey at the University of Kansas in Lawrence. The earth-fill dam is about 130 m long with a maximum height of about 7 m. Beneath the center of the dam is a soil profile about 1–3 m deep that overlies flat-lying Pennsylvanian-aged layers of shale and limestone. The soil thickness tapers to a few centimeters at the ends of the dam. The Lawrence shale dominates the part of the rock section through which the surface waves traveled, although much of the material traversed by the surface waves was in the dam itself.

3. Field geometry

A wheelbarrow-mounted Betsy SeisGun firing 85-gram lead slugs was chosen as a source due to its more uniform and consistent source function in comparison to an 8-kg sledgehammer which was also tested. Receivers were L-40 28 Hz Mark Products geophones mounted on 10 cm spikes. The recording system was two 24-bit 48-channel R48 Geometrics StrataView seismographs networked for simultaneous recording of 96 channels. Record length was 500 ms with a sampling interval of 0.5 ms. We chose 28 Hz geophones because we are mostly concerned about the ultra-shallow case (less than 15 m).

The autojuggie (Fig. 1) consists of 4 steel bars with 12 geophones mounted 18 cm apart on each bar. Each bar with 12 geophones attached was lowered to the ground, planting the geophones automatically and simultaneously into the ground within a few seconds. Previous tests have shown that in order to decrease noise from coupling the steel bars to the autojuggie trailer, it is necessary to disconnect the hydraulic rams from the bars before the data acquisition.

The two parallel survey lines were placed 0.5 m apart. Geophones along the control line were conventionally planted and the autojuggie was used to plant geophones along the test line. Seven shots were acquired along the center line between the two lines of geophones for each spread with shots 2.13 m apart, which equals the length of a bar of 12 geophones on the autojuggie. The offset from the nearest shot to the closest geophone was 8.52 m (the length for the 4 bars, i.e. the total length of the autojuggie geophone spread). Fourteen spreads were obtained, which meant that the entire profile was about 120 m (8.52 m × 14 m) long.

Efficiency was optimized in the field by keeping the geophone spread fixed for seven shots while walking the source away from the spread. At each spread location, the source was moved in 2.13 m increments away from the spread from the initial 8.52 m to a distance of 12.78 m, and then the spread was moved forward along the line by one

Fig. 1. A photo of the autojuggie field layout with the hydraulic cylinders detached from the steel bars to which the geophones are rigidly bolted.

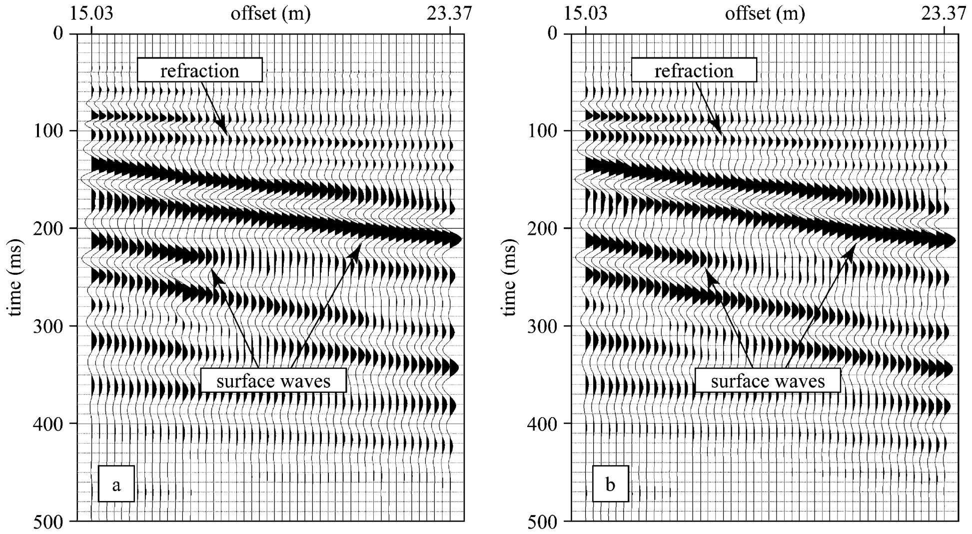

Fig. 2. (a) A typical shot gather from the test line along which the autojuggie was used to plant geophones. (b) A typical shot gather from the control line along which geophones were conventionally planted.

spread-length. This provided continuous geophone coverage along the line at the earth's surface [12]. The multiple shots fired into each geophone spread then resulted in multifold redundancy.

4. Analysis and processing

Two records from two spreads (shot gather with 15.03 m offset to nearest geophones) along two lines (the test and the control line) are shown in Fig. 2. The wave events on the records are visually identical, especially the strong surface waves.

The important feature of surface waves is their dispersion character, which is related to the subsurface velocity structure [13]. In addition, this is the basis of the inversion algorithm in the MASW method. During the MASW process, we should carefully choose preprocessing parameters in muting, automatic gain control, and/or (*f*–*k*) filtering [14] to obtain correct dispersion curves. For the MASW inversion to be stable, the dispersion curves along a line should have a similar wavelength range. For an earth dam case, Rayleigh wave phase velocities generally decrease with increasing frequency.

We used SurfSeis$^{©}$, a commercial software that is available at the Kansas Geological Survey, to process the data. Fig. 3 demonstrated that the two dispersion curves from the test and the control line are quite similar with only slight differences less than 25 m/s. This kind of overall shift difference has little effect on the inversion images of S-wave velocity because the relative velocity contrast within individual dispersion curves is the important parameter.

According to the MASW method, S-wave velocities that are iteratively inverted from the phase velocities of Rayleigh waves using the GLI method will be located at the center of the receiver spread. The inversion results for

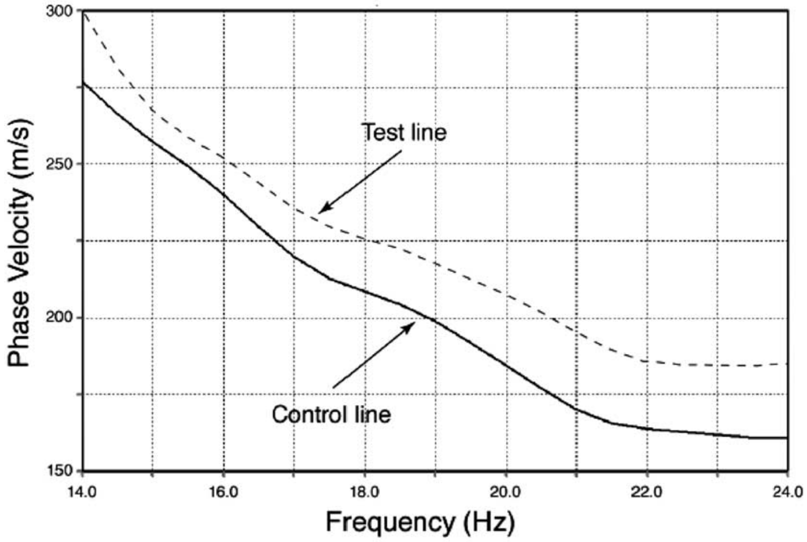

Fig. 3. The comparison of two dispersion curves from the test and the control line.

S-wave velocity along the dam based on those two sets of 14 dispersion curves are shown in Fig. 4(a) and (b).

From the figures, it can be seen that the S-wave velocity of the material in the dam is about 200 m/s or less, which starts at about 16 m from the left end of the section (both shown in Fig. 4). The overall depth for the soil and an S-wave velocity transition zone is about 3 m. The S-wave velocity for the in situ clay is approximately 300 m/s and the depth to the bottom of the dam and soil combined is around 7–8 m. The S-wave velocity for the shale bedrock is over 450 m/s. The white lines drawn on the figures give an interpretation for the dam structure.

5. Discussion and conclusions

According to the spatial sampling theorem [15], if we want to get the S-wave velocity information for a deeper layer, we should use a receiver walkaway technique [1] to increase the length of the spread and use lower frequency geophones (e.g. 4.5 Hz) as well.

Based on the experimental work with MASW on the test and control lines we can conclude that the autojuggie can be used with the MASW method without any variation from the geometry of a CMP survey. This means that we could get useful information from body and surface waves at the same time using high-frequency geophones that are often required for shallow reflection surveys.

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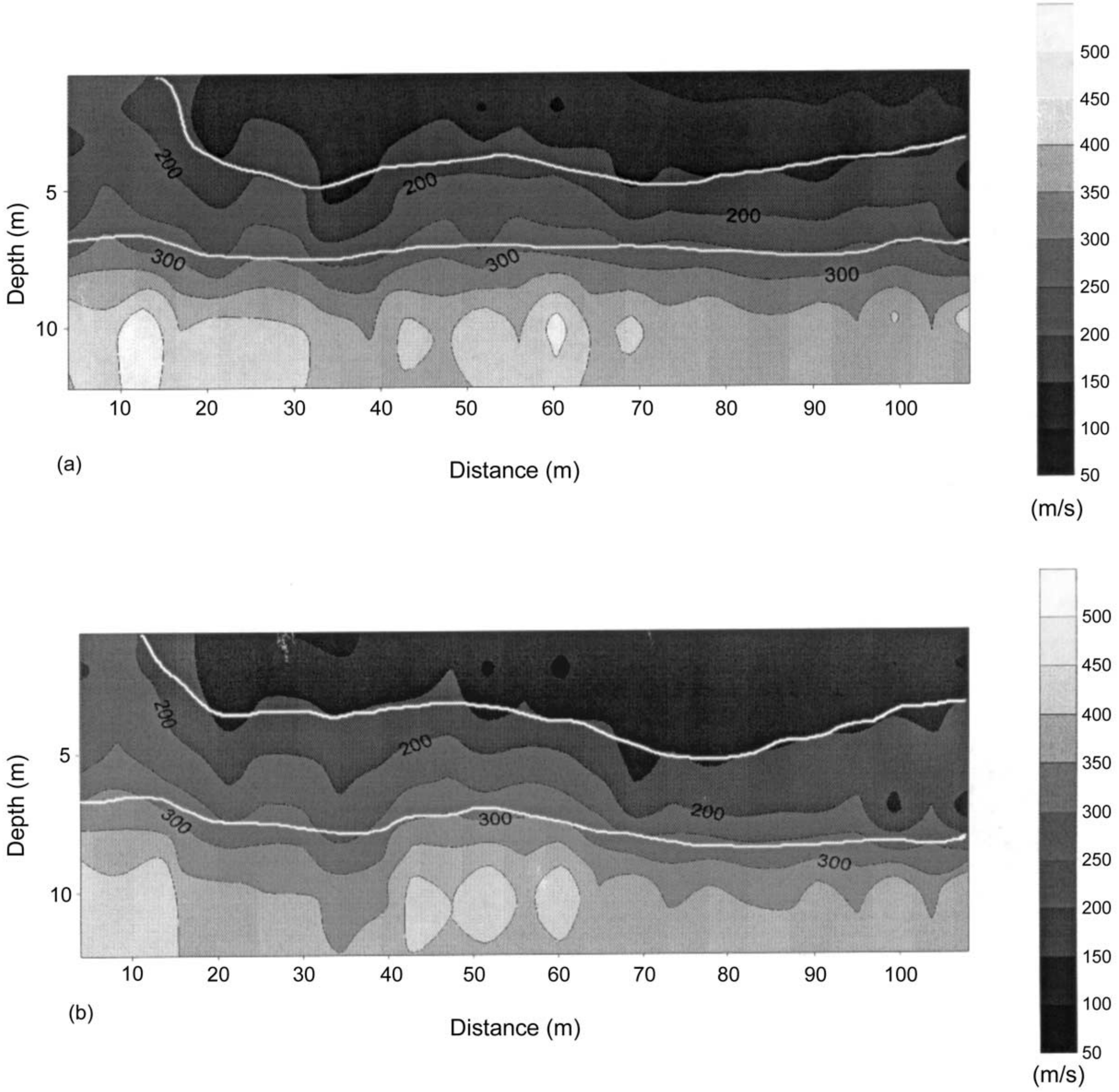

Fig. 4. (a) A 2D S-wave velocity field of the test line along which the autojuggie was used to plant geophones. (b) A 2D S-wave velocity field of the control line along which geophones were conventionally planted.

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