GEOPHYSICS, VOL. 68, NO. 6 (NOVEMBER-DECEMBER 2003); P. 1906–1908, 4 FIGS.
10.1190/1.1635043

Short Note

Useful resorting in surface-wave method with the autojuggie

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INTRODUCTION

The multichannel analysis of surface wave (MASW) method (Park et al., 1999; Xia et al., 1999, 2002a,b) is a relatively new technique. This technique consists (1) acquiring wide-band (∼2 to ∼100 Hz), high-frequency ground roll using a multichannel recording system; (2) creating efficient and accurate algorithms designed to extract and analyze 1D multimodal Rayleigh-wave dispersion curves from ground roll using a basic, robust, and pseudoautomated processing sequence; (3) developing stable and efficient algorithms (Xia et al., 1999) incorporating the minimum number of assumptions necessary to obtain 1D near-surface S-wave velocity profiles using the generalized linear inversion (GLI) method (Xia et al., 1999; Tian and Goulty, 1997); and (4) combining a standard common midpoint (CMP) roll-along acquisition format (Mayne, 1962) with surface-wave inversion of each shot gather to generate a cross-section of S-wave velocity (Xia et al., 1998; Miller et al., 1999). Based on published results (Xia et al., 2002a,b), when calculated with high accuracy, the fundamental mode phase velocities generally can provide reliable S-wave velocities with ±15% relative error.

The autojuggie is designed to plant several dozen geophones automatically in a few seconds (Steeples et al., 1999) using hydraulically powered mechanical systems. The comparisons between the normally planted geophones and multicomponent techniques using the autojuggie are discussed by Spikes et al. (2001) and Ralston et al. (2001), respectively. Their results show that planting many closely spaced geophones simultaneously and automatically can drastically reduce the costs and data-acquisition time in shallow seismic surveys. Their studies also show that data acquired by an autojuggie could produce results equivalent to those obtained by conventional methods as long as the necessary processing is applied.

To analyze the feasibility of using an autojuggie in high-frequency surface-wave surveys, we acquired data along the top of a dam with an autojuggie. A new resorting method, pseudorollaway geometry, was introduced for the autojuggie data to meet the required standard CMP roll-along acquisition format. Two-dimensional S-wave velocity fields with different horizontal sampling intervals were generated for subsequent comparison.

GEOLOGICAL SETTING

The data were collected along the crest 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 to 3 m deep that is underlain by clay which in turn overlies flat-lying Pennsylvanian-age 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 the soil and clay.

FIELD GEOMETRY

A wheelbarrow-mounted Betsy SeisGun firing 85-g lead slugs was chosen as a source because of its more uniform and consistent source function compared with an 8-kg sledgehammer that was also tested. Receivers were L-40 28-Hz Mark Products geophones mounted on 10-cm spikes. The autojuggie (Figure 1) consisted of four 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.

Seven shots were acquired per autojuggie spread with shots 2.16 m apart, where 2.16 m equals the length of a bar of 12 geophones on the autojuggie. The offset for the nearest shot was 8.64 m (the length for the four bars, i.e., the total length

Manuscript received by the Editor May 23, 2002; revised manuscript received April 15, 2003.
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of the autojuggie geophone spread). To save time, there were neither overlaps nor gaps in the geophone spreads. Fourteen autojuggie geophone spreads were obtained, which meant the entire profile across the dam was about 120 m (8.64×14) long.

Because the S-wave velocities obtained by the MASW technique are located at the center of each geophone spread, we appear to get 14 horizontal samples for this particular experiment. However, we devised a new resorting scheme that increases the number of geophone spreads in a pseudorollaway geometry. We thereby increased the number of output S-wave velocity profiles and increased the density of horizontal samples.

ANALYSIS AND PROCESSING

During the MASW process, we carefully chose preprocessing parameters in muting, automatic gain control, and/or f–k filtering (Yilmaz, 2001) to obtain accurate dispersion curves. For MASW inversion stability, the dispersion curves along a line should have a similar wavelength range and thus a similar offset range. The inversion results for S-wave velocity shown in Figure 2 are based on a set of 14 dispersion curves obtained prior to the pseudorollaway sorting. The white lines drawn on the figures show our interpretation for the dam structure. The upper line represents the bottom of the soil profile; the lower line represents the top of Pennsylvanian-age weathered shale beneath the dam.

FIG. 1. The autojuggie field layout.

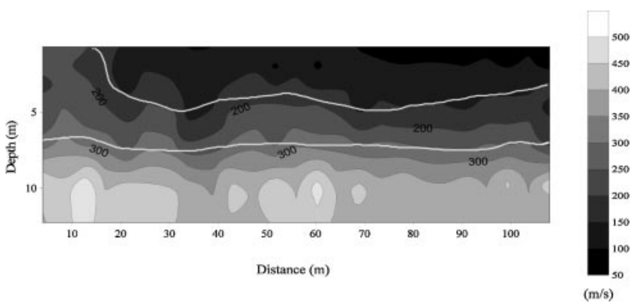

FIG. 2. A 2D S-wave velocity field of the autojuggie line. The upper white line is interpreted as the bottom of the soil profile; the lower one is the top of shale bedrock.

The S-wave velocity of the material in the dam, which starts at about 16 m from the left end of the section, is about 200 m/s or less. The overall depth for the soil and an S-wave velocity transition zone is about 5 m. The S-wave velocity for the in-situ clay beneath the soil is approximately 300 m/s, and the depth to the bottom of the clay and soil combined is around 7 to 8 m. The S-wave velocity for the weathered-shale bedrock is over 450 m/s.

To get the data format required by the MASW method and to increase the density of horizontal samples of the S-wave velocity field, a pseudorollaway geometry was derived by resorting the acquired data. The key to the geometry was to divide a seismic record (48 traces for four bars) into four subrecords (12 traces for each bar). Then the subrecords were sorted to create a new spread with 48 traces in which the subrecords were associated with different shots but each shot was at the same shot location.

Figure 3 shows the pseudorollaway geometry. For instance, the first geophone spread of four bars is identical to the first autojuggie spread acquired under the fourth shot in the first seven-shot run marked by boxed solid squares with 15.12 m offset. The second pseudospread is composed of the three bars marked by boxed open triangles from the first autojuggie spread and one bar marked by boxed solid triangles from the second autojuggie spread. However, these three near-offset bars are under the fifth shot in the first seven-shot run marked by open squares, and one far-offset bar is under the first shot in the second seven-shot run marked by boxed solid squares, where both shots are at the same shot location. The third pseudospread is composed similarly. All of the shots marked by boxed solid squares are the shots used for the spreads in the pseudorollaway spread technique.

In our experimental work, the distance between the two dispersion-curve outputs on two adjacent spreads is 8.64 m. After we adopted the pseudorollaway spread technique, the distance between the two outputs was reduced to 2.16 m (the distance between the center of two adjacent bars). Theoretically, we could obtain the distance between the two adjacent pseudorollaway spreads as close as the distance between two adjacent geophones as long as we have enough shots with similar source signatures. However, we acknowledge that increasing

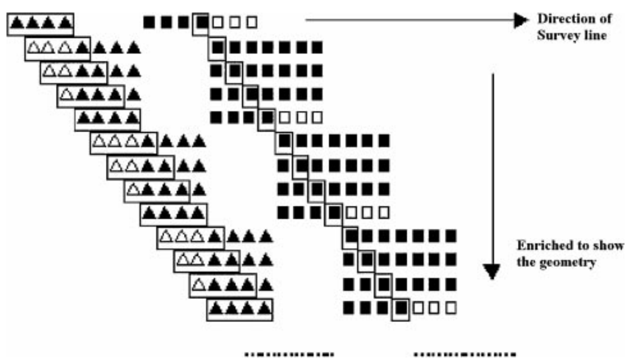

FIG. 3. Diagram for a pseudorollaway geometry. Solid triangles denote a subspread—in this case, a bar. Solid squares stand for a shot. Boxed triangles and squares represent the chosen pseudorollaway spread and its shot position, respectively. The shot (open squares) corresponds to subspread ⊡ but at the location ▣ of vertically down.

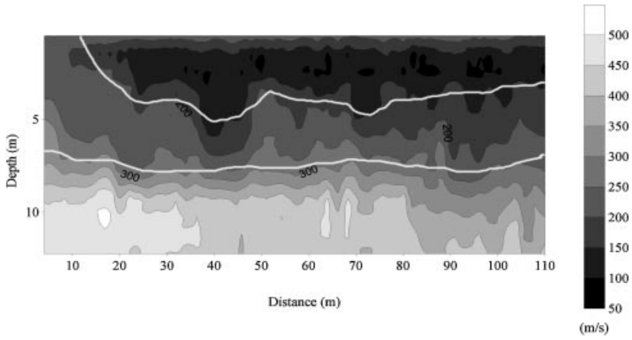

FIG. 4. A 2D S-wave velocity field generated from pseudorollaway spreads along the autojuggie line. The upper white line is interpreted as the bottom of the soil profile; the lower one is the top of shale bedrock.

the horizontal density of S-wave velocity profiles does not necessarily correspond to a higher resolution image.

The new inversion results from 54 geophone spreads using the pseudorollaway geometry are summarized in Figure 4. Compared with Figure 2, the overall features of the dam remain almost the same. However, there is an indication of a higher velocity for the very shallow layer, which might be a result of the air suction (Fredlund and Rahardjo, 1993).

DISCUSSION AND CONCLUSIONS

One needs to increase the spread length to better observe longer wavelengths which sample greater depths in the surface-wave method. If we want S-wave velocity information for a deeper layer, we could use a receiver walkaway technique (Sheriff, 1999) to increase the length of the spread and lower frequency geophones (e.g., 4.5 Hz). In fact, the receiver walkaway technique is a special case of the pseudorollaway spread technique.

Based on the work at the dam, we conclude that an autojuggie can be used with the MASW method with no variation from the geometry of a CMP survey (Spikes et al., 2001). This means we could record useful information from body waves and surface waves at the same time. The pseudorollaway spreads provide more detailed information of the near-surface S-wave velocity distribution within the limits of resolution of the surface-wave method.

ACKNOWLEDGMENTS

This work was supported in part by National Science Foundation grant EAR97061218 and by U.S. Department of Energy contract DE-FG07-97ER14826. The authors thank Matt Ralston, Jason Blair, Paul Vincent, and Elizabeth Johnson of the Department of Geology at the University of Kansas for their assistance in the field tests. The authors thank Lee Blackledge and Mary Brohammer for their efforts on manuscript and graphics preparation.

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