Fixed-source and fixed-receiver walkaway seismic noise tests: A field comparison

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ABSTRACT

Seismologists and geophysical literature often use the term “walkaway” to describe any survey used to analyze wavetrains based on source-to-receiver offset. A distinction should be made between receiver-group moveout (fixed-source walkaway) and source moveout (fixed-receiver walkaway) when multiple channels simultaneously record signal from multiple independent geophones. Three data sets are presented that illustrate this distinction: one collected in an area where a fixed-receiver walkaway survey recorded similar data and was more time efficient than a fixed-source walkaway survey, and two others collected in an area where dipping reflectors and laterally varying velocities caused the fixed-receiver walkaway data to be significantly different than the fixed-source walkaway data. The results show that, while still useful, clarity in recorded data is lost when fixed-receiver walkaway surveys are substituted for fixed-source walkaway surveys in areas with uneven surface topography, dipping interfaces, or laterally varying velocities. This is because walkaway seismograms are displayed by source-to-receiver offset, whereas neighboring traces do not correspond necessarily with neighboring raypaths or reflection points.

INTRODUCTION

The term walkaway is defined as a survey performed by moving source points to progressively larger offsets while keeping geophones fixed, or the source point can remain fixed while the geophones are moved to progressively larger offsets (Sheriff, 2002). Seismic investigations are rarely conducted with a single sensor, and so a distinction must be made between those in which the source is moved and those where the source remains stationary.

The purpose of this paper is to use field-acquired data to demonstrate cases where source-moveout as opposed to receiver-moveout

causes differences in the recorded wavefield. We use the following definitions for fixed-source walkaway (FSW) and fixed-receiver walkaway (FRW) surveys, assuming that multiple channels are being recorded simultaneously. In an FSW survey, the wavefield generated at a single source point is recorded by geophones at stations arranged inline at regular intervals. In an FRW survey, a geophone spread remains stationary, whereas the source location moves out one geophone spread length at a time.

Both FSW and FRW surveys are conducted to determine near-surface seismic phase velocities for various coherent wavetrains. Both can be conducted as stand-alone characterization tools but are used more often to determine optimum receiver interval, sampling rates, and record length for seismic reflection surveys (Knapp and Steeples, 1986). When multiple sources are tested, the resulting seismograms allow the investigator to compare recorded frequency content and predict the minimum source-to-receiver offsets that will be available without clipped data. For most field configurations, an FRW survey is faster and often more convenient to conduct than an FSW. FRW surveys also require a smaller geophone-spread footprint, making them necessary in some areas where geologic or cultural obstacles limit the length of the receiver line.

In homogeneous geologic settings with flat-lying reflectors, the two techniques produce identical source-to-receiver offset-sorted seismograms. However, when the seismic velocity field varies laterally or when target reflectors are dipping (or topography is sloping), the seismic display generated by an FRW differs from the display generated by an FSW. This occurs because FRW surveys contain neighboring traces that do not share neighboring raypaths, resulting in notable differences between the two methods in the presence of lateral variations in subsurface properties (Figure 1).

In this paper, we present a case where an FSW and an FRW survey were conducted in an area with a relatively homogeneous velocity field and flat-lying reflectors to demonstrate the usefulness of the FRW survey in areas with geologically uniform conditions. We then compare two FSW surveys consisting of a single source and 144 geophones to two FRW surveys containing equivalent offsets to the FSW surveys but consisting of 12 sources and 12 geophones. We

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compare the resulting data in the x - t and f - k spaces and demonstrate the loss of clarity encountered when an FRW survey is substituted for an FSW survey in an area with laterally varying near-surface velocities.

Figure 1. Raypaths associated with FSW and FRW surveys. Source (circle-S) and receiver (triangle) locations are displayed by position along a survey line. Corresponding reflection points on a flat-lying reflector are labeled with source-to-receiver offsets in (a) FSW and (b) FRW surveys; (c) and (d) illustrate the different raypaths that two neighboring traces can represent when data collected in FSW and FRW surveys, respectively, are displayed by source-to-receiver offset.

DISCUSSION

Field site I

To demonstrate a situation where an FRW survey produced nearly equivalent results to an FSW survey, we chose a field site where the near-surface velocity field is known to be laterally homogeneous and target reflectors are relatively flat lying. The site chosen is located on the West Campus of The University of Kansas and has been used for several years as a seismic test site. Soil overlies bedrock consisting of Pennsylvanian interbedded shale and limestone. The signal-to-ground-roll ratio for data collected at the site is known to vary with soil-moisture levels, but reflections are often seen at around 35 ms and 75 ms (Jefferson et al., 1998).

The FSW receiver line consisted of 144 Mark Products L-40A 100-Hz geophones planted at 0.2-m intervals. Data were recorded at a sample interval of 0.125 ms by two 72-channel Geometrics StrataView seismographs with 24-bit A/D conversion. We chose a 0.223-caliber rifle fired into an approximately 30-cm-deep pre-punched hole as the seismic source. One source point was set 0.2 m off the end of the receiver line.

The FRW receiver line consisted of 12 identical geophones planted at the same interval as the FSW receiver line. Twelve source points were measured on a tape beginning 0.2 m off the end of the receiver line and continuing at 2.4-m intervals.

Both FSW and FRW data are dominated by ground roll (Figure 2). The FRW recorded an airwave for offsets ranging from ~15–24 m that is not noticeable in the FSW seismogram. This was most likely caused by variations in source-to-ground coupling, tall vegetation, or slight variations in surface topography between the source and the recording receivers. No other obvious variations are visually evident in x - t space. Data are also visually similar in f - k space. Major velocity groupings remain coherent and have similar relative amplitudes. A refraction is seen as the first arrival for offsets greater than ~5 m and has a dominant frequency of ~100 Hz.

This example demonstrates a case where an FRW survey could be used as a cost-efficient noise test. Even though the resulting data sets are equivalent, a distinction still must be made, as different areas in the subsurface have been sampled (Figure 1). Similarity between FRW and FSW data is indicative of relatively homogeneous velocity fields and flat-lying reflectors, not of equivalency between the techniques.

Field site II

Field site II is located adjacent to a tributary stream of the Wakarusa River, approximately 8 km south of Lawrence, Kansas. The survey line crossed an abandoned stream channel, with soil at the surface changing from silt to clay to sand dominated over the length of the line. Alluvial deposits in the area overlie flat-lying, alternating shale and limestone layers. Significant lateral variations in the velocities of the upper ~15 m are caused by a combination of changes in soil composition and moisture content at the site. Direct-wave velocities almost double, and the stacking velocities of sediments above the ~5-m-deep water table reflector vary by ~20% over the length of the receiver line. A topographic survey conducted at the site showed a relief of ~0.6 m along the survey line.

Data for both FSW and FRW surveys were recorded by Mark Products L-40A 100-Hz geophones planted at 0.1-m intervals. Data were recorded at a sample interval of 0.125 ms by two 72-channel Geometrics StrataView seismographs with 24-bit A/D conversion.

We chose a 0.22-caliber rifle firing Remington short rounds into ~ 12 -cm-deep prepunched holes as the seismic source to maximize frequency content and minimize clipped traces.

We conducted the FSW surveys by simultaneously recording 144 traces for a shot located 0.1 m to the east and for a shot located 0.1 m to the west of the east-west-oriented receiver line. These FSW gathers are compared to two data sets recorded by 12 geophones for 12 source points each, creating two FRW gathers with source-to-receiver offsets and orientations equivalent to the FSW surveys. The resulting seismograms simulate the patterns seen in Figure 1.

In x - t space, the FSW surveys recorded distinct direct waves, refractions, and reflections (Figures 3 and 4). The reflector of interest for this particular survey is the water table, visible at 16 ms at 5 m and 27 ms at 12 m offset in Figure 3. This event is not clearly visible in either of the FRW seismograms. The FRW gathers exhibit a distinctive saw-toothed, piecewise appearance, with event breaks corresponding to changes in source location. This is the result of a combination of lateral velocity variations and slight elevation differences between source locations. In both FRW cases, the water table reflection is not readily discernible, and it is difficult to identify the point of transition from direct wave to refracted first-arrivals with increasing offset.

We note that the FRW in Figure 3 shares some common raypaths with the FSW in Figure 4 and conversely. This results from the common raypaths taken by seismic waves recorded by these seismogram pairs. To illustrate, many of the reflection points imaged by the field deployment illustrated in Figure 1b would be duplicated by placing a source at location 0 and receivers at positions 1 through 12 in Figure 1a. As shown in Figure 1a and b, fewer reflection points will be coincident as the survey length and number of source locations are increased.

The difference between the two methods is apparent also in f - k space (Figures 3 and 4), where FSW plots exhibit distinct separation between body- and surface-wave energy (as determined by apparent velocity) but FRW plots have a smeared appearance. Both frequency and apparent wavelength content are markedly different between FSW-FRW pairs. The f - k plot of the FRW survey displayed in Figure 3 exhibits a decrease in apparent surface- and body-wave velocity relative to that seen in the FSW f - k plot. This velocity decrease corresponds to a decrease in dominant frequency and an increase in apparent wavenumber. The f - k plots associated with FRW data displayed in Figure 4, however, exhibit shorter dominant wavelengths and no clear change in the velocity information.

Figure 2. FSW and FRW plots from field site I. FSW data are displayed in (a) and (b); FRW data are displayed in (c) and (d). Direct-arrival (blue arrow), refraction (green arrow), and ground-roll (orange arrow) data are nearly identical in resulting seismograms. Airwave (purple arrow) is more pronounced in the FRW seismogram because of changes in vegetation at the surface. Data are displayed in (a) and (c) x - t space and (b) and (d) f - k space. Data are visually similar between the FRW and FSW displays. Ground roll and signal have been noted in both f - k plots.

Figure 3. FSW and FRW plots from field site II. FSW data is displayed in (a) and (b); FRW data is displayed in (c) and (d), with data displayed in (a) and (c) x - t space and (b) and (d) f - k space. Note differences in reflection quality (red arrow) and direct arrival (blue arrow) and refraction (green arrow) coherency between the FSW and the FRW data in x - t space. Ground roll and signal have been noted in the FSW f - k plot, and the corresponding velocity has been marked in the FRW display.

Figure 4. FSW and FRW plots from field site II. FSW data is displayed in (a) and (b); FRW data is displayed in (c) and (d), with data displayed in (a) and (c) x - t space and (b) and (d) f - k space. Note differences in reflection quality (red arrow) and direct arrival (blue arrow) and refraction (green arrow) coherency between the FSW and the FRW data in x - t space. Ground roll and signal have been noted in the FSW f - k plot, and the corresponding velocity has been marked in the FRW display.

While detailed processing is generally not conducted with noise-test data, it is necessary at times to apply frequency or f - k filters to see reflections or refractions through ground-roll noise. In both FRW data sets collected at this site, the smearing of ground roll and signal placement in f - k space reduces the ability of the processing analyst to use a surgical f - k mute or a frequency filter to remove unwanted noise.

There are advantages to conducting both FRW and FSW surveys in the same area. FSW data can provide stacking velocities, frequency content, and depth to target in such a way that full wavetrains are discernible. An FRW can then provide the investigator with information relating to lateral changes in these properties.

CONCLUSIONS

Because multichannel seismographs have become standard for all aspects of engineering and exploration seismology, distinctions can be made between FSW and FRW surveys. FSW surveys record a

continuous change in the wavefield caused by increased source-to-receiver offset. FRW surveys approximate this by making the assumption that the velocity field is layered and laterally homogeneous, an environment where continuity is not a factor.

Field sites that have laterally homogeneous velocity fields and flat-lying reflectors can be characterized more efficiently by conducting FRW surveys. However, areas with dipping beds and lateral changes in velocity require FSW surveys to obtain coherent wavefields.

The use of FRW surveys to determine optimum survey acquisition parameters for seismic surveys in areas with dipping layers or strong lateral velocity changes can produce erroneous seismic velocity measurements. This may lead to a less-than-ideal survey design, resulting in a negative impact on data quality. Conversely, an FSW may leave the investigator with less information about lateral velocity changes and depth to reflector than could be obtained using both techniques in the same area.

It is important to note that a combination of FSW and FRW surveys could be used as a diagnostic tool to determine the degree of near-surface geologic variability at a site. The information obtained by conducting both an FSW and an FRW could be worth the relatively small additional effort and cost.

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