Roadside Passive MASW Survey — Dynamic Detection of Source Location

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Abstract

In a roadside passive surface-wave survey under a typical urban setting with relatively heavy traffic and a complicated network of roads, a field record usually contains surface wave events generated from multiple source points scattered around the survey location. It is, however, those dominating energy events coming from one common surface point on the road that are used as signal in most advanced dispersion analysis methods based on the 2-D wavefield transformation. Events from other locations interfere adversely with signal events during the analysis if they take comparable energy or are largely ignored in the case of insignificant energy. A long record (e.g., 120 sec) is divided into many subsets of much shorter time of a proper length (e.g., 1 sec) and are treated as independent records of only one (or none) of a dominating event. By utilizing an advanced technique to detect fairly accurately the source location of the event, subsets are processed for their own dispersion images by using the scheme commonly used in the active MASW survey. Multiple data sets of the dispersion image are then stacked to result in an image of the highest signal-to-noise ratio (S/N) ever possible. This is demonstrated by using a field record acquired with a linear receiver array deployed along a busy street that contains events from complex source points and therefore could not be processed for any interpretable dispersion image using other methods currently available.

Introduction

The roadside MASW survey utilizes those surface wave events passively generated from ambient cultural activities, such as traffic. Under the typical urban setting, where a passive surface wave survey often takes place, one relatively long record (e.g., 120 sec) may contain dominating events generated from multiple source points scattered around the survey location due to the heavy traffic in a complicated network of roads. Park (2008; 2009), however, acknowledged it is usually those events of dominating energy originating from one common surface point that are used as signal in the subsequent step of dispersion analysis. The analysis method may be either a stochastic approach by Aki (1957) or a deterministic approach based on the 2-D wavefield transformation technique, which may include the conventional wavenumber method (Kx-Ky) (Claerbout, 1985) or an imaging method by Park et al. (2004). Although strong events from different locations may contribute positively in the process based on the wavefield transformation method if they are well apart in azimuth, they usually interfere adversely with each other due to the limited resolving power for a given recording aperture, which is usually below the degree necessary for any beneficial effects. All other events of relatively insignificant energy are then ignored (or averaged out) during the analysis. This potential harmful effect of multi-source (multi-azimuth) situation appears to exist even with a stochastic approach of the spatial autocorrelation (SPAC) method utilized in the microtremor survey method (MSM) (Aki, 1957; Okada, 2003). In this sense, all dispersion analysis methods of passive surface waves work on this unidirectional (single-azimuth) surface wave events of the most dominating energy as signal. This seems to be the main reason why an excessively long recording time (e.g., a few hundred seconds) has always been necessary to achieve the dominance.

It is, however, possible to utilize all events coming from different source locations if a long record (e.g., 120 sec) is divided into many subsets of much shorter time (e.g., 1 sec). If the length of

subset is properly chosen, then it becomes highly possible for each subset to contain only one event (or none). Then, each subset can be processed independently by using a method by Park (2008; 2009) that treats passive surface waves in a manner the same as would be used from an active survey with a known source location after detecting azimuth and distance of the source point most responsible for the recorded events. This approach is called the passive-with-active (PWA) scheme. An advanced technique (Park, 2010) to detect source location in subsets can show the time variation (e.g., every 1 sec) of azimuth and distance of detected events in a long record. Then, this information is used to apply the PWA method to each subset to produce one data set and dispersion image. Finally, multiple sets of dispersion images are stacked at the end to result in the final dispersion image of the highest signal-to-noise ratio (S/N).

Roadside Passive MASW — Dispersion Analysis

There are a few instances of dispersion imaging techniques recently developed specifically for use with passive surveys of multi-channel recording. Louie (2001) used the slant-stack approach by McMechan and Yedlin (1981) to treat most recorded events as inline propagation from both ends of the linear receiver array. It then claims the banded nature of dispersion image originates from the contribution of possible offline propagations and adopts an empirical scheme to pick the apparently correct phase velocities of inline propagation. This, however, lacks the knowledge of seismic signal processing that tells the banded image originates from the band-limited nature of seismic measurement in time and space (Yilmaz, 1987). Park et al. (2004) introduced a dispersion imaging technique based on the plane-wave propagation. This technique utilizes an azimuth-scanning technique accomplished by extending the conventional wavenumber (Kx-Ky) approach. It utilizes omnidirectional events through a stacking process after resolving azimuth of different events. Its effectiveness, however, is often limited due to the relatively low resolving power for a given size of receiver array. Then, Park and Miller (2008) acknowledged that those source points responsible for dominating events are usually within a finite distance from the receiver array and therefore the propagation should be treated as cylindrical instead of planar. This approach, however, can also produce dispersion images of low resolution and low signal-to-noise ratio (S/N) in the case of complex source points because of the same limitation in resolving power previously mentioned.

Park (2008; 2009) then improved this imaging technique simply by avoiding the azimuth stacking process and simply treating a recorded data set as one of an active survey (Park et al., 1998) after detecting azimuth (and approximate distance) of dominating events, which is in turn made through an improved azimuth-scanning technique introduced in Park et al. (2004). The new imaging technique, called the passive-with-active (PWA) scheme, showed detection of accurate azimuth is far more important than that of the distance and its azimuth detection technique is competent enough to achieve the necessary accuracy. Results from this approach were superb in comparison to those obtained by using other imaging methods by Park et al. (2004), Park and Miller (2008), and Louie (2001). As a consequence, this approach also works on those events of dominating energy generated from one common source point and treats other events as noise.

Dynamic Detection of Source Location (DDSL)

Although under typical urban setting there can be multiple source points scattered around the survey location generating events of comparably dominating energy, these events will very likely take place at different times. Therefore, if a long record is divided into many short (e.g., 1-sec) subsets of a proper length, each of them should contain only one (or none of) dominating event from one particular

source point. Then, each of these subsets can be processed for a dispersion image by using the PWA scheme by Park (2008; 2009). The resultant multiple data sets of dispersion image can then be stacked to improve the overall signal-to-noise ratio (S/N) of the dispersion image.

The original azimuth-scanning method by Park et al. (2004) based on the plane-wave propagation has been extended to account for cylindrical spreading of surface waves, and this improves the detection power of source location in azimuth and distance (Park, 2010). This technique can be applied to the aforementioned subsets to accurately detect source location of the event that may exist in the subset. Output from this new scanning approach consists of amplitude distribution in a 2-D space of azimuth and source distance. Then, the point where the maximum occurs represents the detected source location. By selecting data along the row and column directions at this detected point, respectively, two additional data sets are prepared. One shows amplitude variation along the azimuth axis and the other shows the variation along the source distance axis at different times. This will be illustrated in the next section by using a field data example. The former is called dynamic azimuth scan and the latter is called dynamic source-distance scan. These two output sets can be used for various purposes, including the evaluation of the stacked dispersion image obtained at the end as well as detecting source locations. For those subsets without any significant events, both scans show low amplitudes that can be used to judge whether any specific subset should be discarded from dispersion imaging or not. Once source location is determined from these two sets of scans, then each subset can be processed for its own dispersion image by using the PWA scheme.

Field Record

One field record selected for this study was acquired during the survey conducted on the sidewalk along Clinton Parkway in Lawrence, Kansas, using a 30-channel land streamer of 4.5-Hz geophones with 1.5-m spacing (Figure 1). Other passive MASW surveys were previously conducted near this area (Park and Miller, 2008; Park et al., 2004). The data acquisition was a combination of active and passive MASW surveys performed concurrently using a 20-lb sledge hammer source to apply impacts at 7.2-m inline off the 1st channel of the linear receiver spread that triggered a 120-sec recording with 4-ms sampling interval. The earliest 1-sec portion (Figure 2a) was then used for the active dispersion analysis (Figure 2b), and the remaining 119-sec portion was used for the passive dispersion analysis so that both results could be combined to produce a dispersion image of a wide frequency range that can lead to the final shear-velocity (Vs) profile of a large depth range (Park et al., 2005). The selected record was one of those with events of comparably dominating energy from different source locations and therefore could not lead to any interpretable dispersion image by using any other imaging methods currently available and outlined in the previous section. The 120-sec long record (Figure 3a) shows several prominent events, three of which are randomly selected and displayed in Figures 3b-3d at much a larger time scale. There are, however, many other events of relatively less dominating energy not noticeable in the display of this 120-sec record that exist almost at any instance in the record. Two of the selected events (A and B) show nonlinear arrival patterns indicating cylindrical wave propagation due to the proximity of a source point. The apex of each arrival pattern indicates a possible source point somewhere south of the first half part of the receiver array for event A, whereas it should be south of the second half (or near the end) of the receiver array for event B. The apparent linear arrival pattern of event C indicates a plane-wave propagation originating from a relatively remote source point west of the array.

The passive portion (1-120 sec) of this record was processed for a dispersion image using four different methods currently available: one by Louie (2001) based on the inline plane-wave propagation from both ends of the array (Figure 4a), one by Park et al. (2004) based on stacking of omnidirectional events of plane-wave propagation (Figure 4b), one by Park and Miller (2008) based on the stacking of

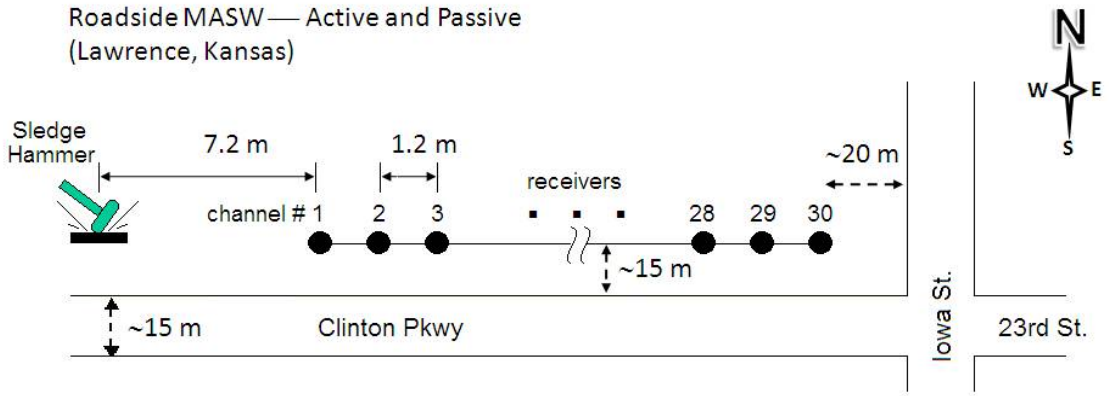

Figure 1. Field layout used in combined (active and passive) MASW survey.

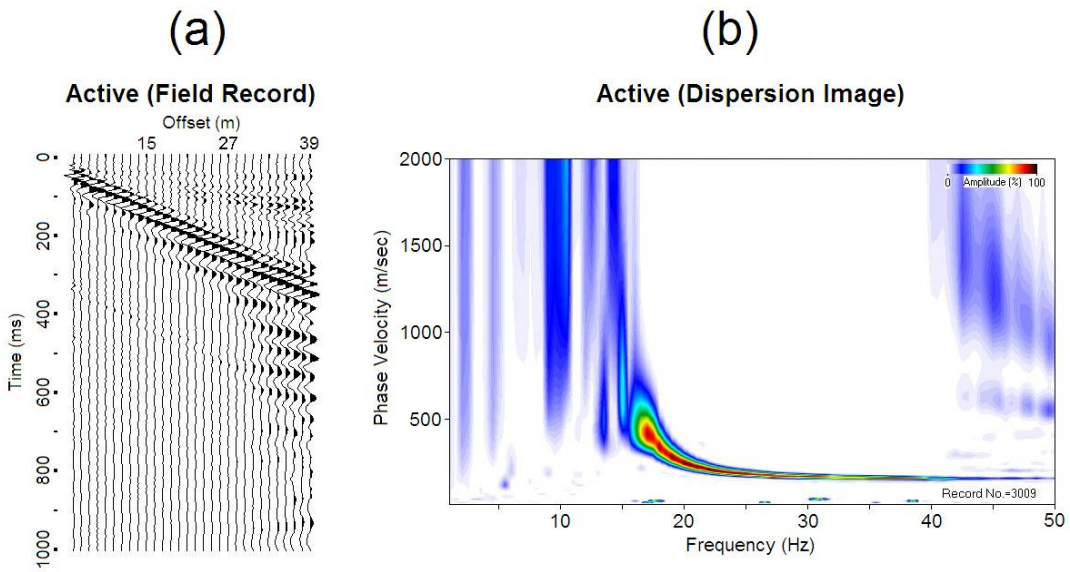

Figure 2. (a) Earliest 1-sec portion of the field record of 120-sec recording time, and (b) its dispersion image.

multi-directional events of cylindrical propagation (Figure 4c), and the PWA scheme by Park (2008; 2009) that treats the events as those of an active survey after detecting the source location responsible for the most dominating events (Figure 4d). The PWA scheme detected the source azimuth had a 300-degree and distance of 50 m, respectively. None of the results show any interpretable image of dispersion due to the events with complex source points.

The passive record is now subdivided into many (119) 1-sec subsets. Then, the source location scanning approach mentioned in previous section (Park, 2010) was applied to each subset in the azimuth range of 180-360 degrees (only two quadrants are necessary with a 1-D receiver array) with 10-degree increments, and in source distance range of 20-500 m with 20-m increments. Scanning results are displayed in Figure 5 in the form of dynamic variation of scanned amplitudes for the azimuth and the distance, respectively. The dynamic azimuth scan (Figure 5a) shows amplitude distribution better focused along the horizontal axis of the target variable (azimuth) than in the dynamic distance scan (Figure 5b), indicating the higher sensitivity achieved with the azimuth scan. For those subsets in

approximately 85-100 sec time intervals, both scans show relatively low amplitudes indicating relatively quiet time intervals without any events of significant energy.

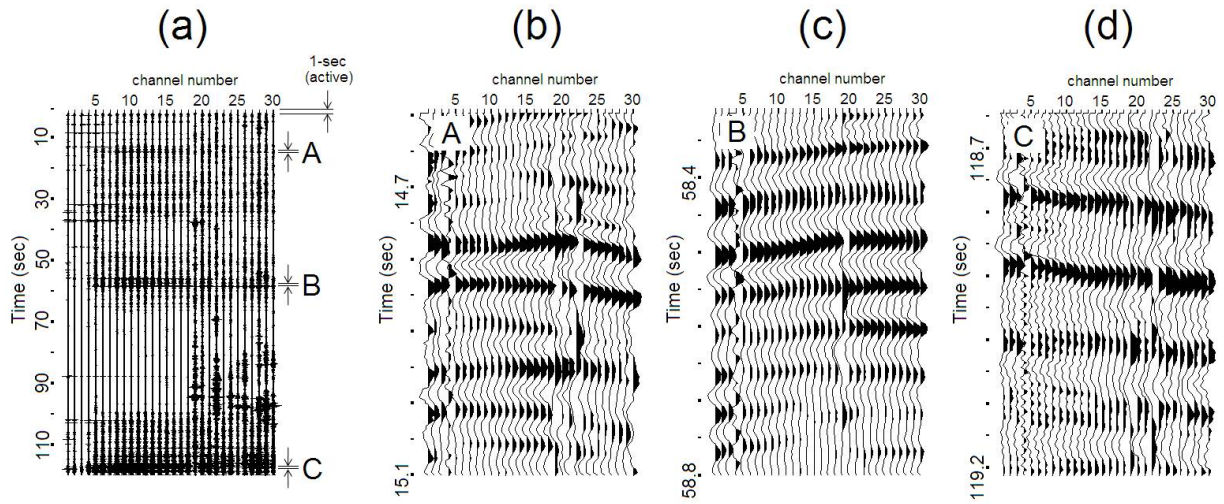

Figure 3. (a) Entire 120-sec part of the field record. Three selected prominent events (A, B, and C) marked in (a) are displayed with enlarged time scales in (b), (c), and (d), respectively.

Double circles marked on both scans indicate those points of azimuth and distance, respectively, picked from the amplitude maxima at each time of subdivisions. Many azimuth picks are shown aligned at around 300 degrees, which is the direction of the Clinton Parkway and Iowa Street intersection where a noticeably rugged road surface was previously identified (Park and Miller, 2008). Picks are also scattered around mostly in the 4th quadrant of south-east direction. Distance picks are clustered around low values around 50-m or less.

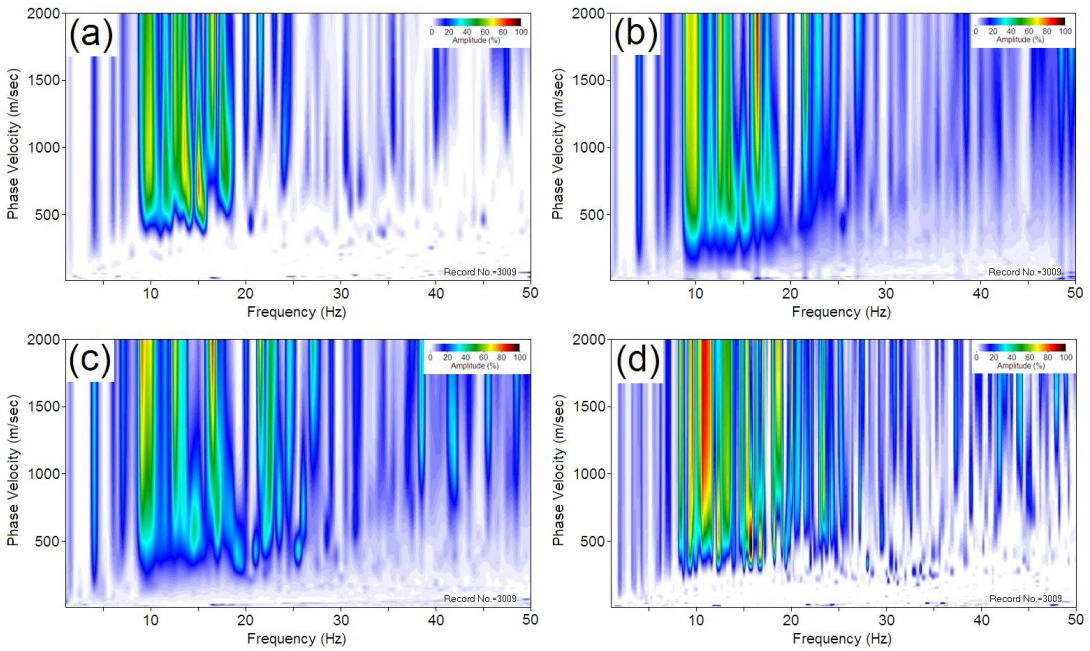

Figure 4. Dispersion images obtained from the passive portion (1-120 sec) of the field record in Figure 3a using four different schemes: (a) Louie (2001), (b) Park et al. (2004), (c) Park and Miller (2008), and (d) Park (2008; 2009).

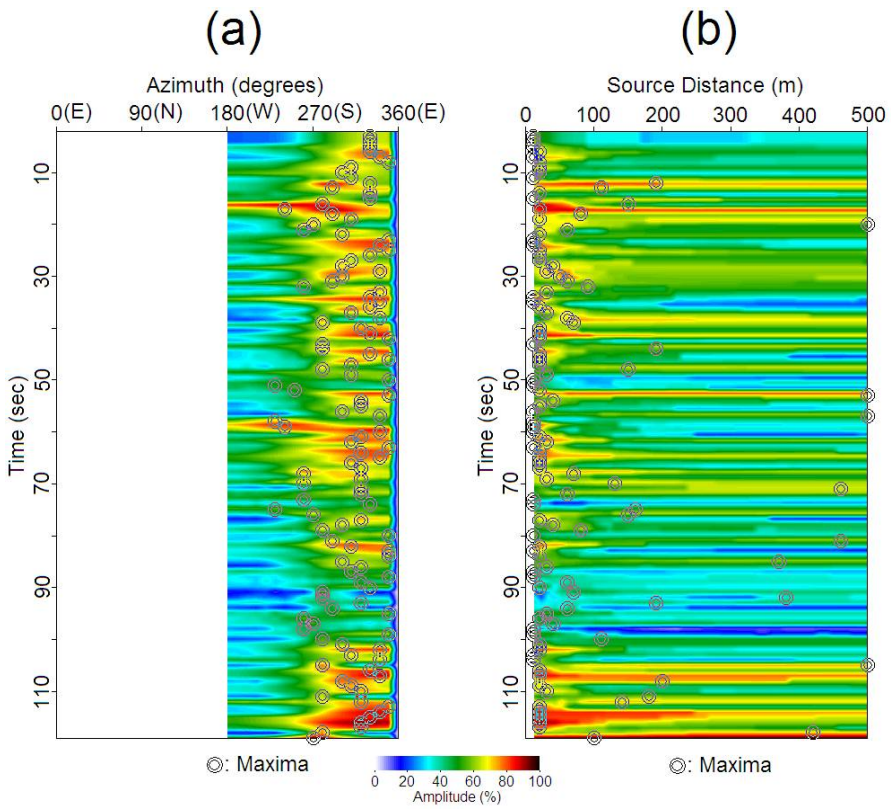

Figure 5. Dynamic (a) azimuth and (b) distance scans obtained from the passive portion (1-120 sec) of the field in Figure 3a by using the source location detection scheme (Park, 2010).

These picked pairs of azimuth and distance at times in the dynamic scans where the azimuth pick had amplitude greater than 50% were then used to apply the PWA scheme to the corresponding subsets. Approximately seventy (70) subsets were processed in this way and data sets of resultant dispersion image were stacked to produce the image shown in Figure 6a. This image clearly shows a dispersion trend at frequencies lower than 20 Hz that none of the previous attempts with other methods could achieve. Figure 6b shows this image combined with the active image previously shown in Figure 2b. A dispersion curve picked from the amplitude maxima at each frequency in this image is superimposed.

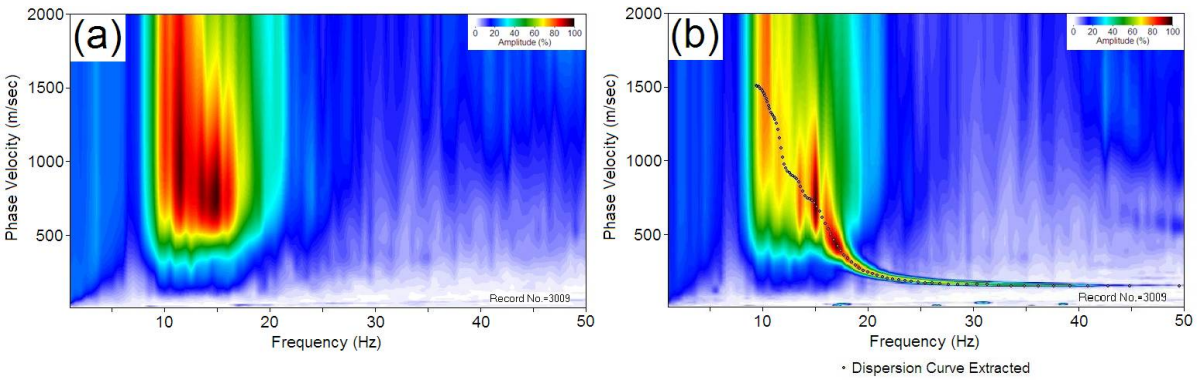

Figure 6. (a) Dispersion image obtained from the passive portion (1-120 sec) of the field record in Figure 3a using the scheme explained in this paper, and (b) its combined image with that from the active portion of the record shown in Figure 2b.

Discussion

There are several processing parameters that can play an important role for the successful outcome of the final stacked dispersion image. Length of the subsets, for example, should be long enough to encapsulate one surface wave event but short enough so they do not include multiple events of different origins. Applying proper tapering on both sides (begin and end) of a subset can also play a role for a smooth image with minimal inclusion of computational artifacts due to an abrupt truncation of wavefields. The advanced approach of source location detection (Park, 2010) could not be explained in any further detail than qualitatively and briefly explained in this paper due to space limitations.

Conclusions

Aided by a method that can detect azimuth and source distance of a surface wave event with a sufficient accuracy, a relatively long passive surface wave record can be divided into multiple subsets of much shorter time to be processed for independent dispersion images. Then, by stacking these dispersion images an image of the highest signal-to-noise ratio (S/N) can be obtained. This approach is especially effective under situations where multiple source points scattered around the survey generate events of relatively strong energy, which is a typical setting for an urban survey.

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