Optimum Field Parameters of an MASW Survey

Choon B. Park,[†] Richard D. Miller,[†] and Hidetoshi Miura[‡]

[†] Kansas Geological Survey, Lawrence, Kansas, USA
[‡] Terra Corporation, Tokyo, 170-0013, Japan

Abstract

The importance of key acquisition parameters of the multichannel analysis of surface wave (MASW) method such as offset, receiver, and source are briefly discussed by using field examples collected over two types of soil sites: the most common type being moderately wet and compact, and the other type being dry and fairly hard. For most common soil sites, the offset range of 10-100 m is optimal for record-ing the fundamental mode surface waves in the frequency range of 5-50 Hz, and in the phase velocity range of 50-1000 m/sec. In general, MASW is a seismic method most tolerant to field parameters among all other methods.

Introduction

In comparison to body-wave survey methods such as reflection or refraction, the surface wave seismic method usually has a far greater tolerance in the selection of optimum field parameters. The main reason for this tolerance is that the surface waves have the strongest energy among all other types of seismic waves, ensuring the highest signal-to-noise ratio (S/N). The recent advent of the multichannel analysis of surface wave (MASW) method (Park et al., 1999; Xia et al., 1999; Miller et al., 1999) has made this specific type of seismic method easier than ever because the multichannel recording and processing method takes advantages of techniques proven during last half century of oil exploration. Nevertheless, selection of some key parameters needs to be discussed before actual surveying takes place. Although this issue was either briefly discussed (Park et al., 1999) or implicitly covered along with other major subjects (Park et al., 1998; 2001) in some of the early publications, the main purpose of this paper is to summarize and refine the criteria based on more extensive field observations. Field parameters discussed include the selection of offset range, source, and receiver.

Minimum Offset (Source-to-Nearest Receiver Distance)

Since the surface wave method requires the analysis of horizontally-travelling plane waves of (fundamental-mode) Rayleigh waves, it is important to avoid recording of any non-planar components. Surface waves become planar (or sometimes called stabilized) only after travell-ing a certain distance from the source, and this distance is known to be a function of wavel-ength (Stokoe et al., 1994; Park et al., 1999). A longer wavelength takes a greater distance before it becomes planar. Although the half-wavelength criterion has been adopted as a rule of thumb in the conventional surface wave method (SASW), our observation with many different field data sets tells us that this rule can be relaxed significantly and the actual distance is a function highly sensitive to the wavelength itself.

In Figures 1a and 1b are shown multichannel field records (shot gathers) collected at two soil sites: a loose and moderately wet soil site near the Kansas Geological Survey (KGS), Lawrence, Kansas; and a fairly hard and dry soil site near Yuma, Arizona. The purpose of the survey at each site was to map the shear-wave velocity (Vs) profile down to a few tens of meters. An IVI

Minivib (a low-power Vibroseis) was used at the KGS site with 10-Hz receivers, and a 20-lb sledgehammer and 4.5-Hz receivers were used for the Yuma site. After some preliminary evaluation of the lowest frequency of surface waves recorded, each record was decomposed into the swept-frequency record (SFR) (Park et al., 1999) in which frequency of each sinusoidal wave increases gradually from the lowest value as marked on the left axis of each display (Figures 1c and 1d). The phase velocity of a specific frequency component of surface waves was calculated from its time-domain slope, and then its wavelength was calculated and marked on the right axis of each SFR figure. The main purpose of this display is to illustrate how each component propagates over the horizontal direction so that the minimum distance to become plane wave can be recognized. The arrival pattern before this distance is reached lacks the familiar linear coherence due to an irregular propagation pattern as observed at the near (< 10m) offsets. It is noted that this distance changes with wavelength. Both SFR records, however, clearly indicate that a source-to-closest receiver distance of 10 m will be enough to assure the plane wave propagation for a wavelength as large as 60 m. Considering the maximum investigation depth is about half the longest wavelength, this can be the optimum distance for the nearest offset as far as the investigation depth is shallower than30 m.

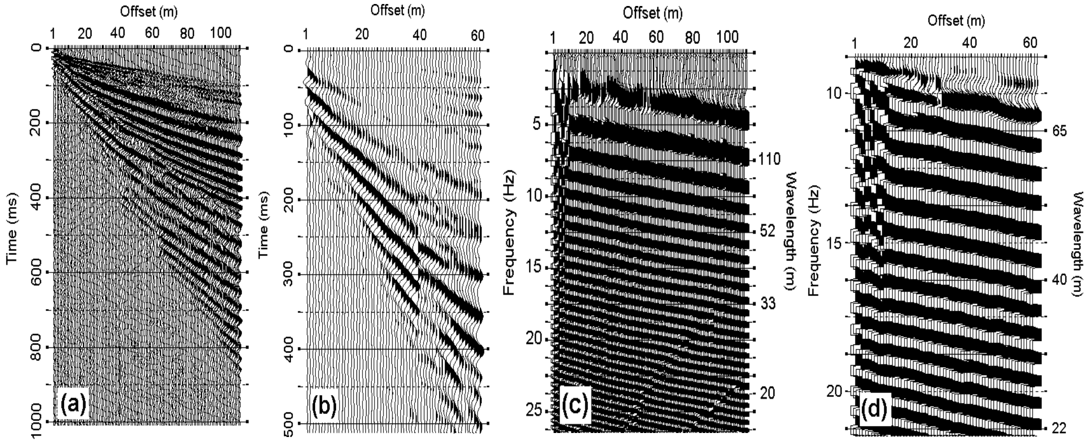

Figure 1. Multichannel records (shot gathers) obtained at (a) Yuma, Arizona, and (b) Kansas Geological Survey (KGS), Lawrence, Kansas. The KGS record was formed by combining two records: one for 1-40 m and another for 41-60 m offset range. Corresponding swept-frequency records are displayed in (c) and (d), respectively.

Maximum Offset (Source-to-Farthest Receiver Distance)

Usually there are two types of waves whose energy may limit the maximum spatial extent of the receiver spread: body waves and higher mode surface waves. Both types of waves tend to dominate over the fundamental mode of surface waves at far offsets and at high frequencies (Park et al., 1998; 1999). The body waves may include refraction event, and often guided waves trapped within the overburden. These waves tend to dominate with offset due to its relatively lower attenuation than surface waves (Figure 2a). Although the relative energy of the higher mode is a complicated function of many parameters including all the layer parameters as well as offset (Tokimatsu et al., 1992), our observation with extensive field records indicates that its domination over the fundamental mode always increases with offset. This is illustrated in Figure 2b by using the Yuma record (Park et al., 2001). Because of this complexity played by both body

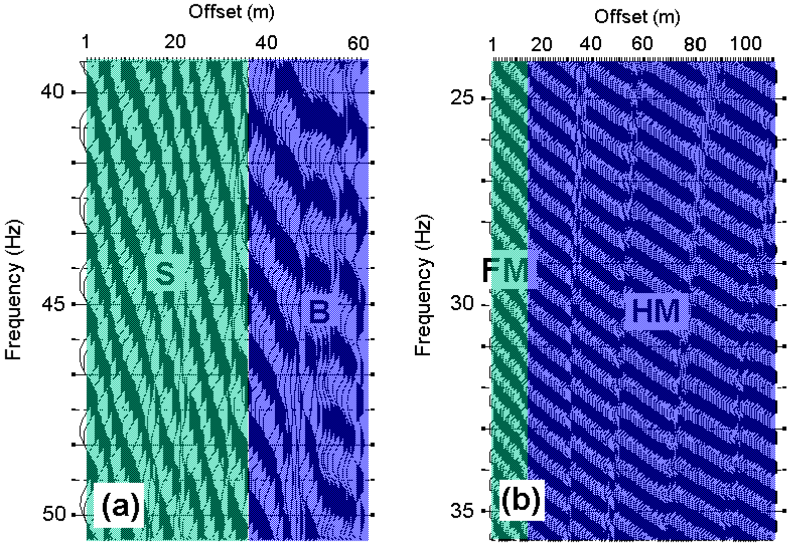

Figure 2. Swept-frequency record of (a) KGS and (b) Yuma data. Domination of body (B) over surface (S) waves at far offsets is noticeable in (a), whereas that of the higher mode (HM) over the fundamental mode (FM) is noticeable in (b).

and surface waves, it seems almost impossible at this moment to assess the maximum offset simply based upon one single parameter, such as wavelength, as in the case of the minimum offset. Instead, we propose an empirical criterion stating it can be as large as 100 m under a normal MASW survey over soil site. This applies when a fairly heavy source is used (for example, a sledgehammer heavier than 10 pounds).

There is another perspective on the farthest offset: the data processing. The resolution of a dispersion curve image increases with the total length of receiver spread (Park et al., 1998; 2001). The resolution issue becomes critical especially when the higher modes tend to take significant energy and need to be separated from the fundamental mode. A longer receiver spread is needed for the lower frequencies of surface waves whose phase velocities are greater than the higher frequencies. The aforementioned criterion of 100 m, however, will be still valid for the most cases.

The importance of a longer receiver spread for a better delineation of dispersion is illustrated in Figure 3 using Yuma data. The overall resolution (sharpness) of the dispersion curve image improves rapidly as the receiver-spread length increases. Also, the low frequency (i.e., large wavelengths) components are acquired only when the spread length is sufficient for them to become well-developed plane waves as explained in the previous section.

When the horizontal variation of near-surface materials does not allow such a long (up to 100 m) receiver spread, then two or more separate surveys may be necessary to focus into different ranges of investigation depths (Park et al., 1999).

Source and Receiver

Dispersion curve images analyzed from three shot gathers collected at the same site, using the same receiver spread but three different seismic sources: 10-lb, 20-lb, and rubber band-aided-weight-drop (RAWD) built at KGS, are shown in Figure 4. These sources are listed in order of increasing impact strength. 40-Hz geophones were the receivers in all three cases. Lower-frequency (e.g., 4.5 Hz) geophones were not used because this testing was oriented toward the body-wave phenomenon rather than the sur-face wave.

It is noted in the figure that there is a slight increase of low-frequency (< 10 Hz) energy as the source changes from10-lb to 20-lb sledge-hammer. However, the maximum impact strength by RAWD resulted in the least amount of low-frequency energy. Instead, the higher mode energy at the higher frequencies (> 30 Hz) increased. This shows that a mere increase of impact strength may not ensure greater energy at lower frequencies. Instead, it seems that changing the coupling mechanism may need to be accompanied with change of source to achieve the desired effect.

At the same site, three different receiver spreads were laid out side by side to test the importance of geophone frequency: Geospace 4.5-Hz, 10-Hz, and 40-Hz geophones (Figure 5). It is obvious that the lower-frequency geophone takes advantage by recording the lower-frequency components of surface waves effectively. However, it is quite astonishing to observe that the lower-frequency limits of the two higher-frequency geophones (10-Hz and 40-Hz) are not limited by their natural frequencies. For example, the10-Hz geophone gave almost an identical result to the 4.5-Hz geophone all the way down to 5 Hz, while the 40-Hz geophone recorded down to about 10 Hz. The dispersion image for the 4.5-Hz geophone, however, clearly indicates that the lowest recordable frequency cannot be lower than 2 or 3 Hz. Therefore, it seems that 10-Hz and 40-Hz geophones can be used to record surface waves as low as 5 Hz and 10 Hz, respectively, in most cases. These lowest frequencies of 5 Hz and 10 Hz usually can be associated with the maximum investigation depths of about 30 m and 15 m, respectively, for most the common soil sites.

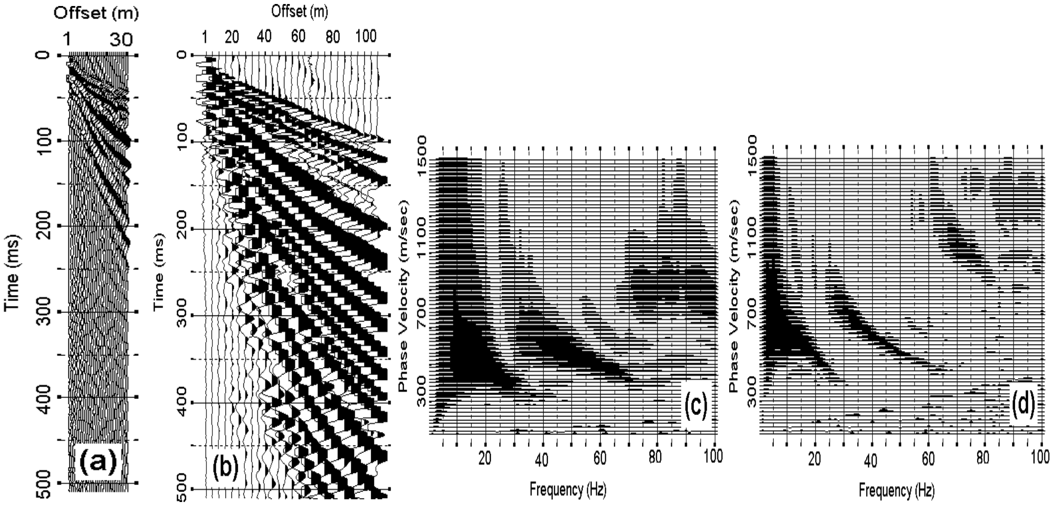

Figure 3. Yuma data with receiver spread length of (a) 30 m and (b) 110 m with the same receiver spacing. Corresponding images of dispersion curves are displayed in (c) and (d), respectively.

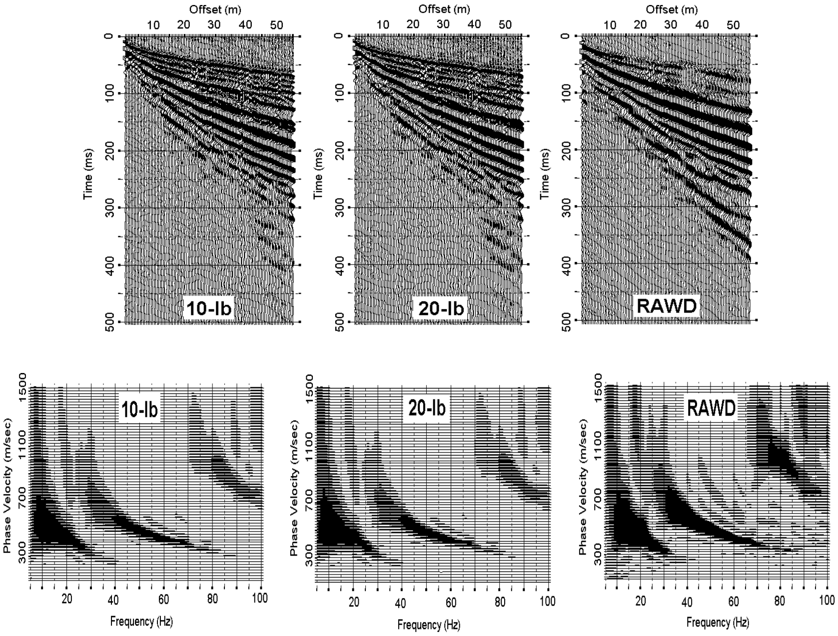

Figure 4. Yuma data collected at the same site using the same receiver spread of 40-Hz geophones but three different seismic sources: 10-lb, 20-lb sledgehammer, and rubber-band-aided-weight-drop (RAWD) built at KGS. Image of dispersion curve is shown below each record.

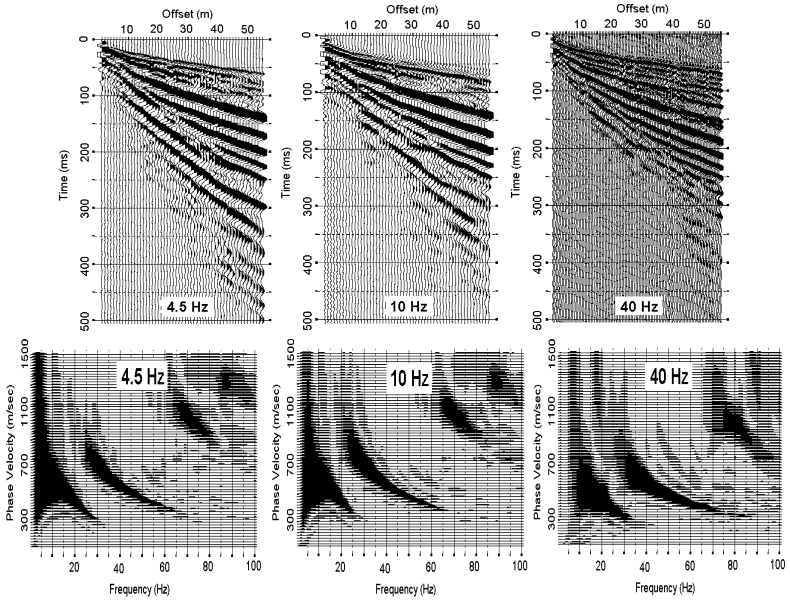

Figure 5. Yuma data collected at the same site using the same seismic source (RAWD) but three different receivers: 4.5-Hz, 10-Hz, and 40-Hz geophones. Image of dispersion curve is shown below each record.

Conclusions

As most of the key acquisition parameters are usually quite tolerant with the MASW survey, the following table may be helpful in drawing vague boundaries for those otherwise-too-open parameters:

Receiver (Hz)	Max. Depth (m)	Minimum Offset (m)	Maximum Offset (m)	Receiver Spacing (m)
4.5	50	10	100	1
10	30	10	100	1
40	15	10	100	1

Table 1: Optimum field parameters for MASW surveys for most common soil sites. A seismic source of 10-lb or heavier sledgehammer and use of recording instrument with 24-bit or higher dynamic range are both assumed. No low-cut analog filter should be used during the acquisition.

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