

OFFSET AND RESOLUTION OF DISPERSION CURVE IN MULTICHANNEL ANALYSIS OF SURFACE WAVES (MASW)

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Summary

Influence of offset-related parameters on the resolution of dispersion curve in multichannel analysis of surface waves (MASW) surveys is described from the theoretical perspective of the dispersion curve imaging method used during a normal implementation of MASW. The examined parameters include total number of channels (or traces), closest-to-source offset, receiver spacing, and total length of the receiver spread. The influences of different phase velocities and frequencies are also briefly described. It is shown that a larger total receiver spread length is always preferred to produce a higher resolution. This means that with a given number of channels available a greater receiver spacing is preferred as long as it does not cause a spatial aliasing problem. This shows that with MASW method the general notion that more channels are always better can be misleading.

Introduction

The multichannel analysis of surface waves (MASW) method (Park et al., 1999; Xia et al., 1999) utilizes horizontally traveling Rayleigh-type surface waves to extract the near-surface elastic properties. It has been applied to various projects such as seismic characterization of pavements (Park et al., 2001a; Ryden et al., 2001), mapping 2-D bedrock surface (Miller et al., 1999a), weak spots (Miller et al., 1999b), Poisson's ratio distribution (Ivanov et al., 2000a), generation of shear-wave velocity (V_s) profiles (Xia et al., 1999b), detection of voids (Park et al., 1998b), and seismic characterization of sea-bottom sediments (Park et al., 2000b; Ivanov et al., 2000b).

As with any other surface wave method, accurate extraction of multimodal dispersion curves is the most critical part of the analysis with the MASW method because most of its applications have this information as the most fundamental data at the start. The extraction method then may change with the perspective on the nature of the surface wave generation and propagation. The simplest perspective would be the assumption that the surface wave consists of a single-mode (fundamental mode) only as with the conventional method that calculates the phase velocity from the measurements at only two different surface locations. Actual surface-wave phenomena, however, often go far beyond this simple state due to the inclusion of disturbing factors such as higher modes of surface waves (Park et al., 1998a) and body-wave events (Park et al., 1999). A more advanced method that accounts for these disturbing factors can take place only through the multichannel method.

The optimum acquisition parameters in the MASW technique are those that can assure the most accurate dispersion curve analysis during a subsequent data processing step. Then, the criteria on the optimum changes with the specific processing technique. In a broad sense, three different types of processing techniques are currently available; frequency-wave number ($f-k$) (Gariels et al., 1987), slant-stack ($t-p$) (McMechan and Yedlin, 1981), and the one by Park et al. (1998). Although a brief and comparative description of each method has been previously presented (Park et al., 2000a; 1998a), a more detailed description will be available in Park et al. (2000a). At this moment we claim that the method by Park et al. (2000a) results in the most accurate extraction of multimodal dispersion curves under a wide range of realistic situations.

In this study we analyze how offset-related parameters influence the resolution of dispersion curves imaged by Park et al. (2000a; 1998a). The parameters include the total number of traces (N) in one multichannel record being analyzed, closest-to-source offset (dx_1), receiver spacing (dx), and total length (X) of receiver spread.

Analytic Framework of Dispersion Analysis with MASW

Multimodal dispersion curve analysis is based on the following assumptions about the nature of surface waves:

1. Multimodal surface waves originate from the same source wave $r_{(0)}(t)$ generated at the source point that has an intrinsic amplitude $A_0(\omega)$ and phase $\Phi(\omega)$ functions determined only by the source characteristics and elastic properties of the layer model at the source point.
2. As far as one frequency ω is concerned, the relative amplitude $\kappa^{(k)}$ of a specific k -th mode remains constant with respect to the amplitudes of other modes over the surface distance covered by one multichannel record.
3. Phase difference $\varphi^{(k)}(\omega)$ for frequency ω between two surface points separated by dx of a specific k -th mode is determined as $\varphi^{(k)}(\omega) = \omega dx / C_\omega^{(k)}$ where $C_\omega^{(k)}$ = phase velocity of k -th mode at frequency ω .

The validity of each assumption is discussed in Park et al. (2000a).

Imaging of dispersion curves is then created through a wavefield transformation that maps surface wavefields from the offset-time (x - t) domain into the phase velocity-frequency (v - ω) domain. In the v - ω domain, resolution of the created image can be examined through the following formula (Park et al., 2000a):

$$S_N^{(m)}(v, \omega) = \sum_{k=0}^m z_{(k)}^\xi \left(\frac{1 - z_{(k)}^N}{1 - z_{(k)}} \right) \kappa^{(k)} R_0^{(0)}(\omega), \text{ with } z_{(k)} = e^{j\omega dx \left(\frac{1}{v} - \frac{1}{C_\omega^{(k)}} \right)}, \quad (1)$$

where $S_N^{(m)}(v, \omega)$ is the amplitude of the transformed wavefields summed over offset (x) for N different traces and m different modes (k), $\xi = dx_1/dx$, $R_0(\omega) = A_0(\omega)e^{-j\Phi(\omega)}$ (i.e., Fourier transform of the source wave at $x = 0$), $\kappa^{(k)}$ = a constant for k -th mode, and subscripts (or superscripts) in parentheses indicate the mode number.

The trend of peaks in $S_N^{(m)}(v, \omega)$ creates images of the dispersion curves. Since $S_N^{(m)}(v, \omega)$ is a complex number, two different terms can be examined in association with the geophysical meaning (Claerbout, 1985): absolute value and real-part of the complex number. It is shown in Park et al. (2000a) that the absolute-value approach, in general, results in an image with a lower resolution than the real-part approach does. However, the resolution is much less affected by the complexity of the phase uncertainty $\Phi(\omega)$ of the source wave than the real-part approach is. Because of this reason, it is shown that the absolute-value approach is preferred when $\Phi(\omega)$ is a complicated function of frequency ω (this is usually the case in the near-surface investigation). Although the phase uncertainty problem can be overcome with the real-part approach through a more involved analysis (Park et al., 2000a), the absolute-value approach is used in this paper because it is simpler.

Total Number of Traces

The total number of traces (N) here means the number of traces included in a single data set being analyzed for dispersion curves. It is the same as number of channels used if one shot gather is being analyzed. However, multiple number of shot gathers can be grouped together to make one multichannel record by using the walkaway format approach (Dobrin and Savit, 1988). In this case, there are additional disturbing factors to be accounted for that may arise due to inconsistency in $\Phi(\omega)$ and also in timebreak (Park et al., 2000a) between the different shot gathers. These factors may disturb the analysis for both absolute-value and real-part approaches.

Different N 's can be associated with either different X 's (fixed dx) or different dx 's (fixed X). Figure 1 shows the resolution [the trend of $S_N^{(m)}(v, \omega)$ as v changes] in the former case. In this modeling, three modes ($m = 3$) (fundamental mode, and first and second overtones) are included with phase velocities of each mode as $C_\omega^{(0)} = 150$ m/sec, $C_\omega^{(1)} = 210$ m/sec, $C_\omega^{(2)} = 300$ m/sec at 25 Hz, and the amplitude of each mode as $\kappa^{(0)} = 0.25$, $\kappa^{(1)} = 1.5$, $\kappa^{(2)} = 0.75$. It is clear that the more number of traces results in the higher resolution. Figure 2 illustrates the same effect by using a real (60-channel) shot gather collected over a soil site in San Jose, California. Influence of the different N 's resulting from different dx 's (with fixed X) is illustrated in Figure 3. It is shown that the smaller N with a larger dx does not cause any appreciable change in the resolution. An excessively coarse spatial sampling ($dx = 5$ m), however, raises the spatial aliasing problem. Figure 4 illustrates the influence of N by using a real data set.

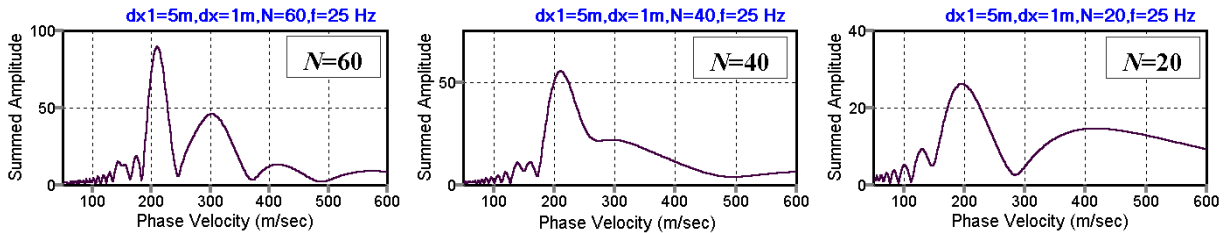


Figure 1. Changing trend of the absolute value of equation (1) that illustrates how the resolution (the peaks at 150 m/sec, 200 m/sec, and 300 m/sec) changes with the total number of traces (with a fixed dx).

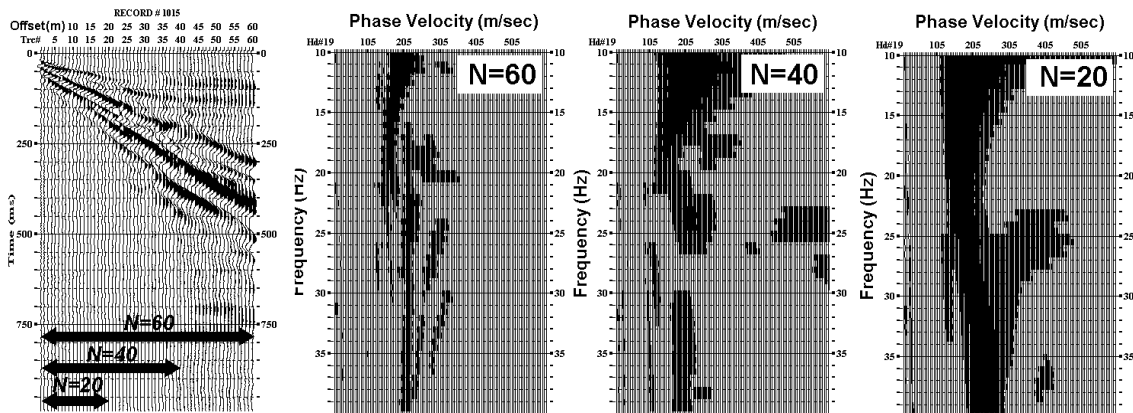


Figure 2. Experiments with different number of total traces from a 60-ch shot gather ($dx = 1$ m) collected at San Jose, CA. It is obvious that the greatest number (60) produces the highest resolution that images dispersion curves of several higher modes.

Offsets

When it comes to offset (x), three different parameters can be examined; the closest-to-source offset (dx_1), receiver spacing (dx), and the total length (X) of the receiver spread. dx_1 is a parameter that can be associated with general closeness of all receivers to the source. Figure 5 shows that changing of dx_1 does not cause any significant change in the resolution. The influence of X can be examined in two different ways; by changing dx (with fixed N) or by changing N (with fixed dx). The latter case has been discussed previously in association with total number of traces (N) (Figure 1). Figure 6 shows the influence under the former case. In this figure it is shown that the greater X results in the higher resolution. However, an X achieved by an excessive dx runs into the spatial aliasing problem as shown in the case of $dx = 5$ m.

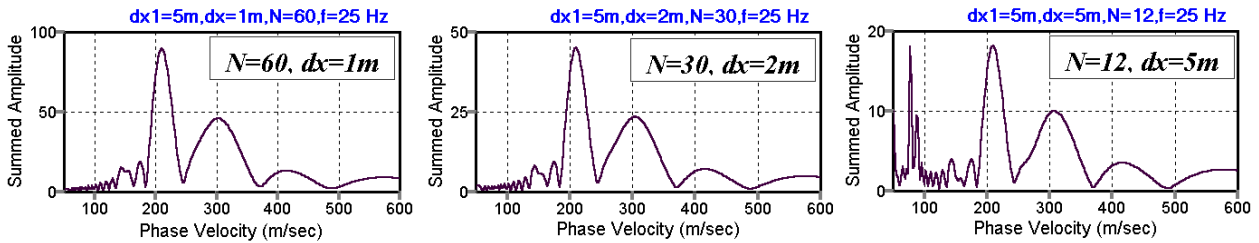


Figure 3. Changing trend of the absolute value of equation (1) that illustrates how the resolution changes with the total number of traces (with a fixed total length X of receiver spread).

Discussions

The influence of some key acquisition parameters on the resultant resolution of the dispersion curve image has been examined. The examination was performed purely from the formulistic perspective of the theory represented by (1). Although it may appear that those key parameters can be determined from this perspective only, in reality there are always other factors that need to be taken into consideration. Among them are the near-field and far-field effects (Park et al., 1999) that may limit the closest and farthest distance of receivers from the source. There are also the issues of lateral inhomogeneity and surface objects disturbing the measurements. Sometimes all these factors may play a more important role than the formulistic perspective does in the determination of optimum offsets.

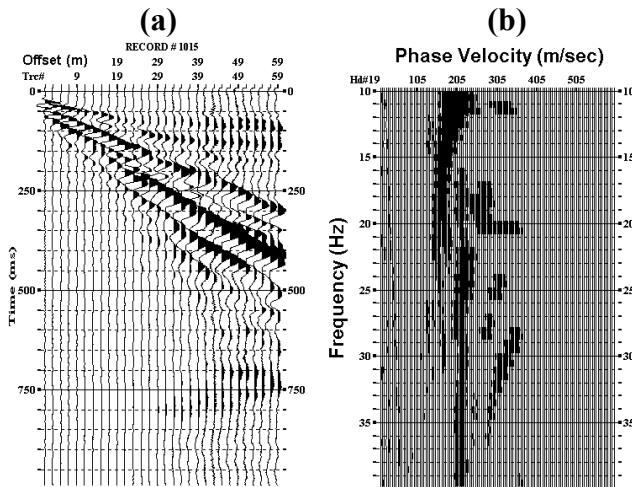


Figure 4. (a) A 30-trace shot gather ($dx = 2$ m) obtained from the 60-channel shot gather in Figure 2 through a spatial resampling (every other trace), and (b) its corresponding dispersion curve image that shows the same resolution with the 60-trace shot gather.

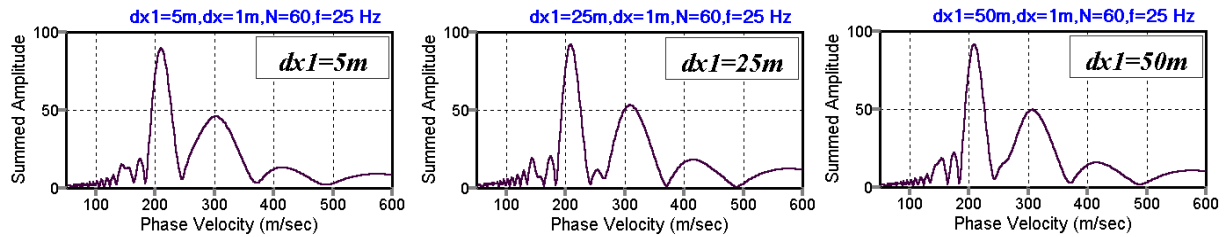


Figure 5. Changing trend of the absolute value of equation (1) that illustrates how the resolution changes with general closeness (dx_1) of the receiver spread to the source.

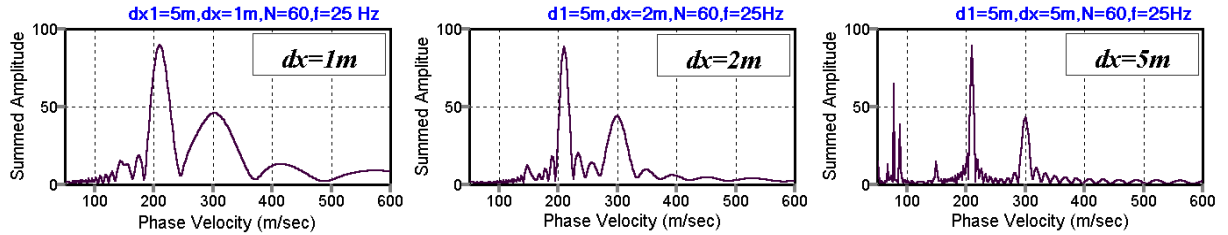


Figure 6. Changing trend of the absolute value of equation (1) that illustrates how the resolution changes with the total length X of the receiver spread achieved from the change in receiver spacing (dx).

Conclusions

From only theoretical perspective of the dispersion curve analysis with the MASW method, the followings can be concluded:

- A higher number of channels (traces) can always result in the higher-resolution dispersion curve image only if it is associated with the longer receiver spread length (X). There is no benefit in a mere increase of N not accompanied by the increase in X .
- The longer receiver spacing (dx) is always preferred as long as it does not cause the spatial aliasing problem.

During an actual field survey, however, above consideration should be made only after an assessment of the near-field, far-field, and lateral inhomogeneity effects has been made.

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