DETECTION OF NEAR-SURFACE VOIDS USING SURFACE WAVE

Choon Byong Park, Richard D. Miller, and Jianghai Xia
Kansas Geological Survey
University of Kansas
1930 Constant Avenue, Campus West
Lawrence, Kansas 66047-3726

ABSTRACT

Ground roll is displayed, on an uncorrelated field record obtained using a monotonic sweep, in increasing or decreasing order of frequency with each frequency well separated from all others. Phase velocity and attenuation characteristics of each frequency contain the average elastic property of near-surface materials down to approximately half the wavelength. Uncorrelated field record, therefore, by itself can be associated with a two-dimensional display of the change in near-surface elastic property. Through the redundancy in data acquisition and a simple data processing step, the uncorrelated field records can be transformed into a stacked section that can be correlated directly to image of the change in elastic property of near-surface materials with respect to a certain reference location. This method can be effectively used to detect near-surface anomalies of various kinds.

INTRODUCTION

Penetration depth of ground roll, that represents depth of a zone through which the bulk of ground roll propagates, changes with wavelength: the longer wavelength penetrates deeper (Figure 1). When elastic property of the near-surface materials changes with depth, ground roll then becomes dispersive: propagation velocity changes with frequency. The propagation velocity, normally called phase velocity, is determined mainly by the average elastic property of medium within the penetration depth. Therefore, dispersive character of ground roll can be utilized to investigate the change in elastic property of near-surface materials.

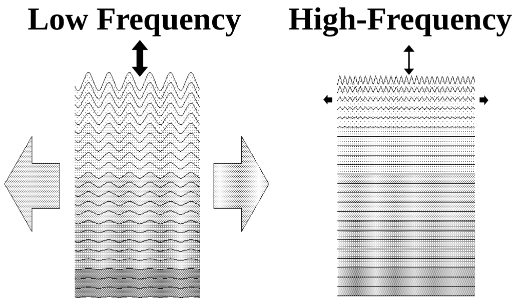

Figure 1. Penetration depth of ground roll changes with frequency.

When multi-channel recording method is employed, the elastic property of near-surface materials can be investigated not only in vertical but also in horizontal directions. In this case, the horizontal change will result in the change not only in phase velocity but also in attenuation characteristics for those frequencies penetrating through the area of change. These two types of change will be observed on multi-channel record as changes in linear slope and amplitudes of recorded waves.

When a swept-source like Vibroseis is used, each frequency component of ground roll is recorded with an excellent separation from other components with little interference effect on uncorrelated field record (Park et al., 1996). Furthermore, when sweep changes in a monotonic fashion (e.g., linearly) with time, the recording time can be correlated directly to a depth that represents the approximate depth of penetration. Therefore, both vertical and horizontal change of near-surface elastic property can be investigated through various kinds of data analysis.

We present a simple technique that can lead to construction of a near-surface image representing a contrast in elastic property with respect to a reference location. Multiple number of shot gathers are collected over a certain surface distance in a similar fashion to the conventional roll-along mode for common-depth-point (CDP) survey. Obtained shot gathers are then corrected for the offset effect by using a phase-velocity function analyzed from a shot gather at a reference location. All the traces in one shot gather are then stacked together to make one stacked trace. The stacked section consisting of all these stacked traces then shows an image of the change in elastic property of near-surface materials. This method is tested in the field by detecting a near-surface steam tunnel.

SURFACE-WAVE RESPONSE TO NEAR-SURFACE ANOMALY

A near-surface anomaly is defined here as part of near-surface materials that have elastic properties significantly different from those of the rest parts that are termed as normal zones. The transition from normal to anomaly zone may be either abrupt or gradual.

During a ground-roll survey, the near-surface anomaly will leave signature of its presence on multi-channel record in several forms. One commonest form would be different phase velocities for those frequencies propagating through or near the anomaly. Another form would be different attenuation characteristics.

Besides different phase velocities and attenuation characteristics, an anomaly may reveal its presence in the form of generation of higher modes (Bath, 1973; Gucunski and Woods, 1991), reflected and diffracted (Yanovskaya, 1989; Sheu et al., 1988) ground roll. Generation of the higher modes is closely related to existence of low-velocity zone underlain by and overlying high-velocity zones (a zone of velocity inversion) (Stokoe et al., 1994) and energy of the higher modes tends to become more significant for high frequencies (short wavelengths) (Tokimatsu et al., 1992). Reflected and diffracted ground roll will be generated if the transition from normal to anomaly zone is abrupt. All these types of signature of an anomaly may appear on a multi-channel record when either the source or receivers are located at or near the surface location of the anomaly.

Theoretically, surface waves cannot penetrate through a void filled with air or fluid because of the lack of shear modulus inside the void. However, considering the retrograde elliptical motion of mass under ground roll disturbance, those surface waves that penetrate near or deeper than the void with dimension of elliptical motion significantly exceeding the dimension of the void may still propagate horizontally only with influenced propagation characteristics in either attenuation or phase velocity or both.

DATA PROCSEEING PROCEDURE

Dynamic linear move out (DLMO) correction is applied to each shot gather to correct for the offset effect, therefore, to flatten the linearly sloping events of ground roll. The correction is a dynamic operation because the amount of correction changes with time as well as offset. DLMO can be accomplished in frequency domain as follows:

$$W_{DLMO}(f,x) = e^{j\Phi_f} W(f,x), \qquad (1)$$

where

$W(f,x)$ = Fourier transform applied to time axis of a shot gather, $w(t,x)$,
$W_{DLMO}(f,x)$ = Fourier transform of DLMO-corrected shot gather, $w_{DLMO}(t,x)$,
$\Phi_f = 2\pi fx / C_f$, and
C_f = phase velocity for frequency *f*.

C_f used in DLMO correction is calculated from a shot gather obtained at a reference location. The reference location is a presumably normal zone within the survey line. All traces in a DLMO-corrected shot gather are then stacked together to produce one stacked trace per shot.

Above procedure achieves following effects after stacking:

- Those frequencies that have the same phase velocity as that at the reference location will have large stacked amplitudes through constructive interference.
- For those shot gathers obtained at or near surface location of anomaly, DLMO correction will result stacked traces of weak amplitudes through destructive interference.
- All the higher modes will be attenuated through destructive interference because of their different phase velocities.
- All nonplanar, reflected, and diffracted ground rolls (and possibly any body-wave events) will be attenuated through destructive interference because of their nonlinear occurrence on a multi-channel record.
- Random noise will be attenuated.

When stacked traces are displayed, all the normal zones will show large amplitudes and the anomalous zones will be denoted by attenuated amplitudes. Degree of the attenuation will be proportional to the degree of being anomalous with respect to the reference location.

FIELD TEST — DETECTION OF UNDERGROUND STEAM TUNNEL

An experiment was executed as a feasibility check of the method previously outlined to detect a near-surface steam tunnel as an anomaly. A soccer field in the campus of Kansas University, Lawrence, Kansas, was chosen as a test site where an underground steam tunnel (4 ft. x 7 ft.) crosses under the field at depth of 7 ft. (Figure 2).

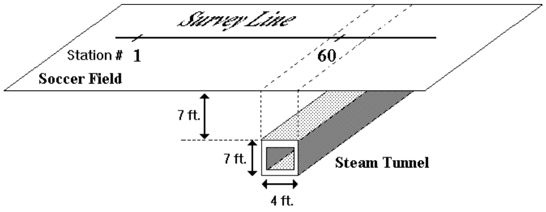

Figure 2. A diagram showing field geometry and location of steam tunnel.

Both shot and receiver intervals were 2 ft., and 30 receiver groups of 10-Hz geophones were laid out. The source-to-first receiver was 48 ft. Total 70 shot gathers were collected. Acquisition started in such a way that first several shot gathers could be collected with both source and receivers being kept well out of the surface location of the steam tunnel. An IVI Mini-Vib was used as source with 10 Hz - 150 Hz linear sweep with 10-s sweep time. Due to a condition in source operation the clean sinusoidal wave could be generated only at frequencies higher than 15 Hz.

A dispersion curve was constructed from the first five shot gathers by using a method by Park et al. (1998) (Figure 3). It represents a fundamental-mode dispersion curve averaged over a surface distance covered by the five shot gathers. This dispersion data were then used for the dynamic linear move out (DLMO) correction of all the obtained shot gathers. Figure 4 shows early part of the stacked section of all these DLMO-corrected shot gathers. Depth scale is shown along with time scale. To display depth scale in increasing order, the corresponding portion of the stacked data was flipped over and therefore time scale is displayed in decreasing order. The depth scale represents half the penetration depth (one wavelength). Therefore, any feature interpreted from the stacked section should be linked to the average elastic property at the corresponding depth at the reference location.

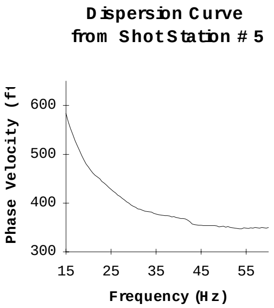

Figure 3. Dispersion curve from reference location.

Existence of the tunnel is obvious on the stacked section as indicated by an approximately rectangular zone with weak amplitudes. Accuracy of the image is remarkable considering the generally-accepted notion that surface wave method is an average method. Along with the tunnel image are other anomalies at various other shallower parts noticeable. These anomalies may be related to different moisture contents of the soil that affect the bulk density, or to different types of soil used during the construction of the tunnel and soccer field.

DISCUSSIONS

The method of imaging with ground roll outlined is one of the simplest form of seismic survey that can be implemented as either a separate survey or a byproduct of body-wave survey. Despite its simplicity, the outcome can find invaluable usage in many applications. Examination of shot gathers indicates that those shot gathers collected with source on top of the tunnel have much higher phase velocities and severer attenuation for those frequencies contributing to the tunnel image on the stacked section. This indicates possibility of the generation of higher modes and therefore indicates that the existence of tunnel may have played a similar role to the existence of a velocity inversion. Signature of ground roll seems to become more pronounced when source, instead of receivers, locates on top of anomaly as indicated by the comparison of the shot-gather stack with receiver-gather stack (Figure 5). It seems possible to achieve similar result from shot gathers collected using impulsive sources like sledge hammer. We are currently executing research on this topic.

Stack of DLMO-Corrected Shot Gathers

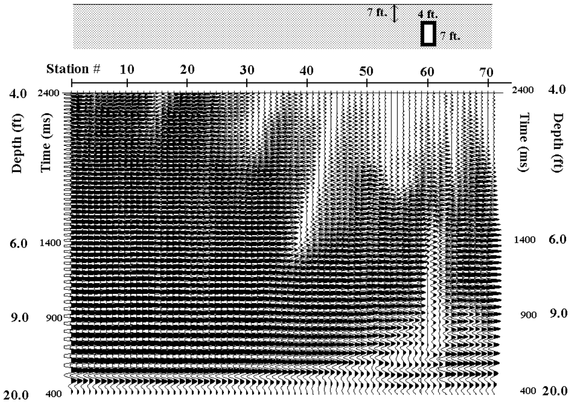

Figure 4. Stacked section of shot gather after dynamic linear move out (DLMO) correction.

Stack of DLMO-Corrected Receiver Gathers

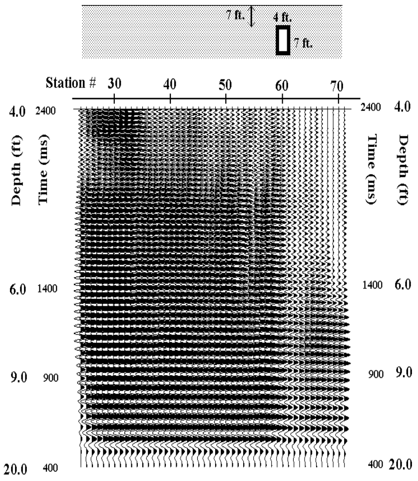

Figure 5. Stacked section of receiver gathers after dynamic linear move out (DLMO) correction.

CONCLUSIONS

Based upon the well-known concept of ground roll that it travels horizontally along the near surface with different frequencies mapping elastic property of materials at different depths, it is possible to image near-surface anomaly through a simplest form of data acquisition using a swept source and through a simplest form of data processing without intensive analysis. Signature of near-surface anomaly seems to become more pronounced on multi-channel record when source locates at surface location of anomaly than when receivers do.

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