Journal of Applied Geophysics 84 (2012) 52–60

Contents lists available at SciVerse ScienceDirect

Journal of Applied Geophysics

journal homepage: www.elsevier.com/locate/jappgeo

Numerical investigation of MASW applications in presence of surface topography

Chong Zeng [a,*], Jianghai Xia [a,1], Richard D. Miller [b], Georgios P. Tsoflias [c], Zhejiang Wang [d]

[a] University of Kansas, Kansas Geological Survey, Lawrence, KS, USA
[b] Kansas Geological Survey, The University of Kansas, 1930 Constant Ave., Lawrence, KS 66047, USA
[c] Department of Geology, The University of Kansas, 1475 Jayhawk Blvd. Lindley 120, Lawrence, KS 66045, USA
[d] College of Geo-Exploration Science and Technology, Jilin University, 6 Ximinzhu St., Changchun, Jilin 130026, China

ARTICLE INFO

Article history:
Received 19 January 2012
Accepted 12 June 2012
Available online 20 June 2012

Keywords:
MASW
Topography
Finite difference
Levee
Rayleigh waves
Dispersion

ABSTRACT

In the applications of multichannel analysis of surface waves (MASW), dispersion curves are usually picked in an energy tracing manner on dispersion images. They are compared with the theoretical dispersion curves based on a horizontally layered earth model during the subsequent inversion for shear-wave velocities. Surface topography can strongly influence energy distribution on a dispersion image. In theory, static correction should be applied to seismic records before generating dispersion images if there are any elevation variations along a two-dimensional (2D) survey line. The out-of-plane noise from side areas of a survey line in three dimensions (3D) can also contaminate the recorded wavefield. We synthesize the seismograms through finite-difference modeling for 12 types of 2D earth models that represent the basic elements of topography along a survey line. The dispersion images are compared with the corresponding theoretical dispersion curves that are calculated by ignoring the topography of the models. The comparison shows that errors of the picked Rayleigh-wave phase velocities can be constrained within 4% if a slope angle of the topography is less than about 10°. For steeper topography, errors of the picked phase velocities are greater than 4% and static correction are recommended before the dispersion analysis. In the 3D case, we investigate a set of 3D levee-shaped earth models to evaluate the errors caused by the out-of-plane noise from the edge of an embankment. The analysis suggests that the distance between the edge of an embankment and a MASW survey line should be at least 1/10 of the dominant Rayleigh-wave wavelength so that energy distortion on dispersion images due to topography are less significant than that caused by other noises.

1. Introduction

Multichannel analysis of surface waves (MASW) is a non-invasive method to estimate shear (S)-wave velocities in shallow layers by inverting phase velocities of surface waves (typically Rayleigh waves) (e.g., Song et al., 1989; Xia et al., 1999). It has been widely used in various geophysical investigations for environmental and engineering problems over the past two decades (e.g., Luo et al., 2009b; Miller et al., 1999; Xia et al., 2002a, 2003). In a 2D application of MASW, a shot gather containing strong Rayleigh-wave energy is acquired through a multichannel recording system. Then a dispersion image that represents the energy distribution of the wavefield is generated by transferring the shot gather into frequency–velocity (f–v) domain. Because the Rayleigh-wave energy is dominant on most near-surface seismic records (Xia et al., 2002b), the dispersion curves of Rayleigh waves can be picked by tracing the high-energy concentration on the dispersion image. These dispersion curves describe the variation of Rayleigh-wave phase velocities in different frequencies. They are used as inputs of subsequent inversion for S-wave velocities.

The precision of an input Rayleigh-wave dispersion curve is crucial to the accuracy of the inverted S-wave velocities. For a commonly used one-dimensional (1D) layered earth model, the Rayleigh-wave phase velocity C_r is a function of frequency f, S-wave velocity v_s, P-wave velocity v_p, mass density ρ, and layer thickness h (Xia et al., 1999). By giving the dispersion curves (data set of C_r and f) and the physical parameters in each layer (v_p, ρ, and h), the S-wave velocities can be solved through the damping least-square inversion scheme presented by Xia et al. (1999) or some nonlinear inversion methods such as the genetic algorithm (e.g., Dal Moro et al., 2007; Liang et al., 2008; Nagai et al., 2005). Dispersion curve is the most important input for MASW inversion since it is essential to evaluating the misfit function during each step of the iterations. Any inaccuracy of the calculated phase velocities on the dispersion curve will be directly introduced to the inversion and smear the final solution.

There are two basic assumptions for all dispersion curve based inversion methods. First, the earth model must be laterally homogeneous. Second, the free surface of the earth model must be

* Corresponding author at: BGP International Inc., 10630 Haddington Dr., Houston, TX 77043, USA. Tel.: +1 713 465 2999; fax: +1 713 465 9777.
E-mail address: zengchong@gmail.com (C. Zeng).
[1] Present address: The China University of Geosciences, Subsurface Imaging and Sensing Laboratory, Institute of Geophysics and Geomatics, Wuhan, Hubei, China.

0926-9851/$ – see front matter © 2012 Elsevier B.V. All rights reserved.
doi:10.1016/j.jappgeo.2012.06.004

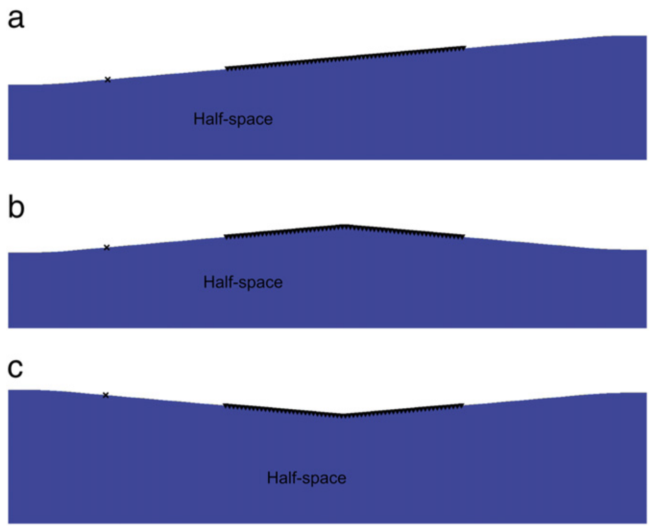

Fig. 1. The homogeneous half-space earth model whose free surface contains a) a slope, b) a ridge, and c) a valley. The cross indicates the location of the point source. The triangles represent receivers. In b) and c), the center of the receiver array is exactly located on the peak/nadir of the ridge/valley.

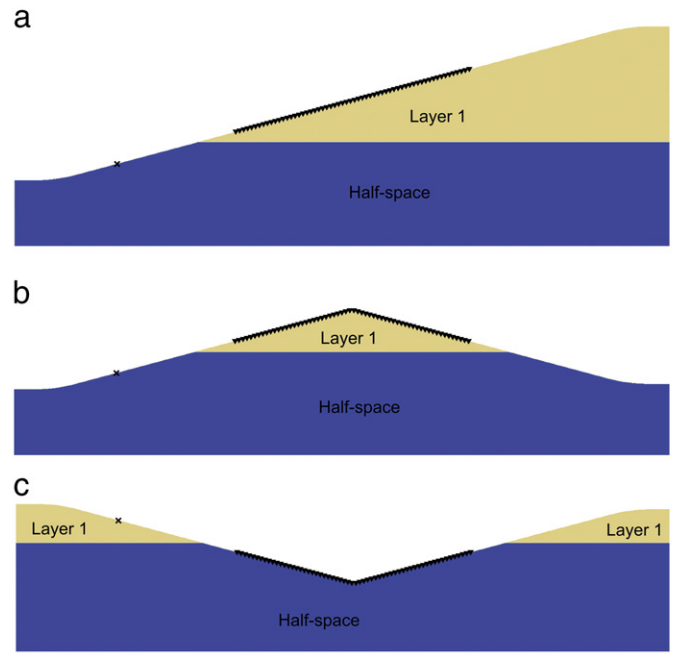

Fig. 3. The two-layer earth model whose free surface contains a) a slope, b) a ridge, and c) a valley. The interface is horizontal. The cross indicates the location of the source. The triangles represent receivers. The source is on the half-space and the receivers are on layer 1. The source and the receiver array are located on difference media.

horizontal. These assumptions are required because the theoretical dispersion curves can be calculated only under these conditions. The first assumption is appropriate for many environmental and engineering problems. For example, the layered structures formed by depositions in different geological ages are very common in the near surface. In engineering investigations, many human-made targets such as roadbeds are well-layered constructions. However, the second assumption of a horizontal free surface is not applicable in many cases because the real earth is far from flat in a local scale. Receivers are usually not located in a same elevation due to the topography of the earth surface formed by weathering, deformation, etc. Strictly speaking, static correction should be applied to the seismic record before generating dispersion images if there are any elevation variations. Otherwise the energy concentration on the dispersion images will be distorted due to the topography. In this case, it is difficult to pick an accurate dispersion curve by the conventional energy tracing method. This could introduce huge errors to the subsequent inversion in many real-world applications of MASW. Moreover, the theoretical horizontal flat earth model may be no longer suitable to approximate the real earth when the topography is significant.

Besides the elevation change along a receiver array, noise from the out-of-plane area that a 2D survey line does not cover can also contaminate the recorded wavefield because the real world is always 3D. Surface topography beyond a vertical 2D survey plane can generate multiples and other complicated wave phenomena that propagate in oblique directions. The amplitude of this type of noise can be as high as the effective Rayleigh waves that propagate inside the survey plane. In this case, spurious energy concentrations will appear on dispersion images and make it challenging to pick dispersion curves by tracing the peak values of energy. A typical example of this situation is to perform an MASW survey along the axis of a dam or a railroad,

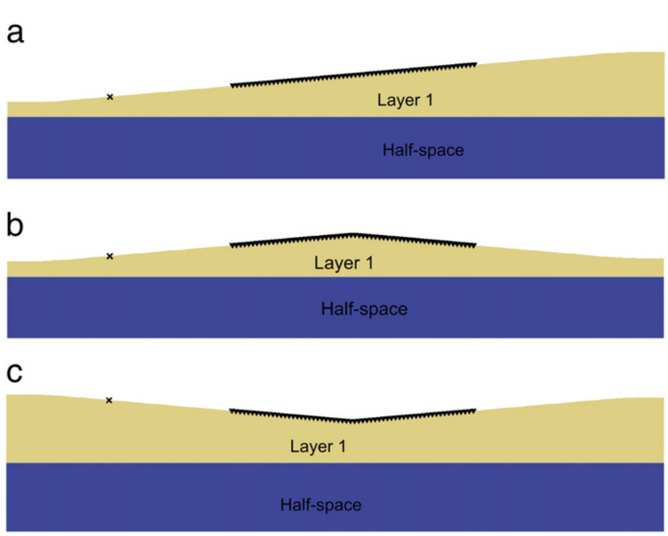

Fig. 2. The two-layer earth model whose free surface contains a) a slope, b) a ridge, and c) a valley. The interface is horizontal. The cross indicates the location of the source. The triangles represent receivers. In b) and c), the center of the receiver array is exactly located on the peak/nadir of the ridge/valley. Both the source and receivers are on layer 1.

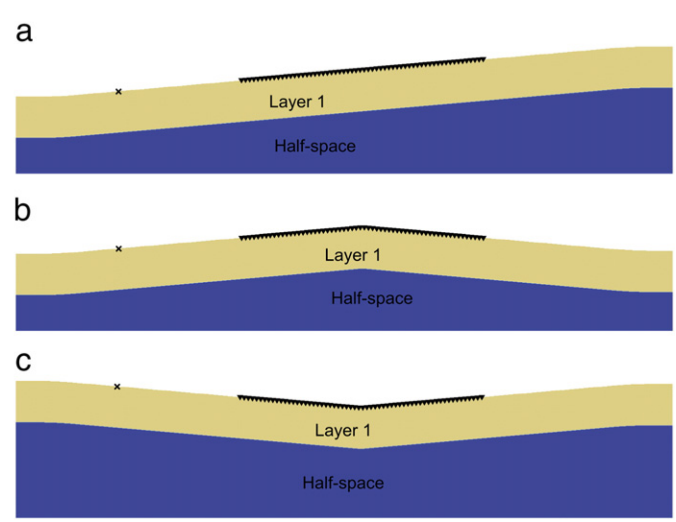

Fig. 4. The two-layer earth model whose free surface contains a) a slope, b) a ridge, and c) a valley. The curvature of the interface is the same as the topographic free surface. The cross indicates the location of the point source. The triangles represent receivers. In b) and c), the center of the receiver array is exactly located on the peak/nadir of the ridge/valley. Both the source and receiver array are on layer 1.