유사파형역산에 의한 천부의 속도-경계면 모델 결정
Determination of Shallow Velocity-Interface Model by Pseudo Full Waveform Inversion

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개요 본 연구에서는 천부지층모델의 정보를 얻기 위해 굴절법 탄성과 탐사주시로 부터 굴곡된 지층경계면의 형태와 지층속도를 주파수 영역에서의 유사파형 역산에 의해 파악하는 방법을 연구하였다. 역산 수행에 필요한 합성주시와 자코비안을 효과적으로 계산하기 위해 지층의 경계면을 직선으로 구획화하여 이에 대한 발사 파선추적법을 고안하였다.

본 연구에서 개발한 역산법의 타당성과 정확성을 검토해 보기 위해 지표지형과 지하지층 경계면이 굴곡된 모형지층에 대해 역산해 보았으며 그 결과 모형지층의 형태와 속도를 정확하게 역산하였다.

본 역산법은 지형변화가 심한 지역이나 지층경계면이 복잡한 지질구조에서의 반사법 자료의 정보정 및 굴절법 자료 해석에 활용될 수 있을 것이며, 토목 건축 등 시설 부지 탐사에 유용하게 사용될 수 있을 것이다.

Key words : 굴절법 탄성파탐사, 주파수 영역, 파선추적, 지형변화, 부지탐사

1. Introduction

Seismic refraction techniques have been widely used to map regional velocities and structures and to delineate the shallow subsurface. In particular, refraction data inversion has been used for a long time to calculate static corrections(Russell, 1989) and to estimate the shallow velocity-depth model (Hampson and Russell,1984 ; Docherty,1992 ; Landa et al.,1995).

In this paper, we propose a way to reduce the picking procedure for the inversion of refraction data. The first step is to pick rough refraction events (We do not have pick exact arrival time, and mute the seismic events following the rough picks). The second step is to estimate the wavelet by selecting first arrival waveform of some traces and use it for deconvolution in the frequency domain. In this way, we can obtain the frequency component of head wave data and use them for the pseudo waveform inversion.

We used the damped least-squares method (which is the Gauss Newton method) for the inversion of head wave data. We calibrate this inversion method by using both synthetic and real data cases.

2. Theory

To calculate the traveltimes of a head wave, we assume that the subsurface can be divided into blocky regions consisting of straight-line segments and that the head waves travel along the interface, as shown in Figure 1. We obtain the traveltime of the head wave from source to receiver to be

$$T = \sum_{k=1}^{K}\left(\frac{r_k}{v(r_k)}\right) \tag{1}$$

where, K is the number of ray path segments, $v(r_k)$ is the velocity of the medium through which the ray passes, r_k is the distance defined as

$$r_k = \sqrt{(x_{k+1}-x_k)^2 + (z_{k+1}-z_k)^2} \qquad k = 1,2,3,\cdots,K$$

where, K is the number of ray path segments, and x_k and z_k are the coordinates of the points indicated in Figure 1. Figure 2(a) and 2(b) show the head wave ray paths computed using our shooting algorithm.

The key point to note is that we will take the Fourier transform of Equation (1) to obtain a representation for the head wave in the frequency domain. Fourier transforming of Equation (1) gives

$$U(\omega) = \exp(i\omega T) = \exp\left(i\omega\sum_{k=1}^{K}\left(\frac{r_k}{v(r_k)}\right)\right) \tag{2}$$

The partial derivatives of Equation(2) with respect to interface coordinates are given by :

$$\frac{\partial U(\omega)}{\partial x_k} = i\omega\left(\frac{x_k - x_{k-1}}{v(r_{k-1})\ r_{k-1}} - \frac{x_{k+1} - x_k}{v(r_k)\ r_k}\right) U(\omega) \tag{3}$$

and

$$\frac{\partial U(\omega)}{\partial z_k} = i\omega\left(\frac{z_k - z_{k-1}}{v(r_{k-1})\ r_{k-1}} - \frac{z_{k+1} - z_k}{v(r_k)\ r_k}\right) U(\omega) \tag{4}$$

where $k = 1,2,3,\cdots,K$.

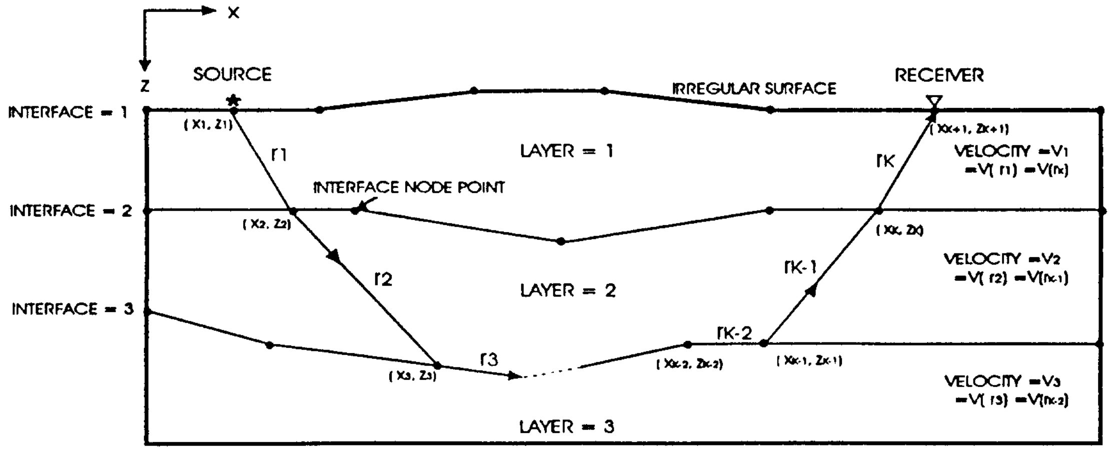

Fig. 1. Ray path in a model with irregular interfaces. Interfaces are assumed to consist of straight line segments.

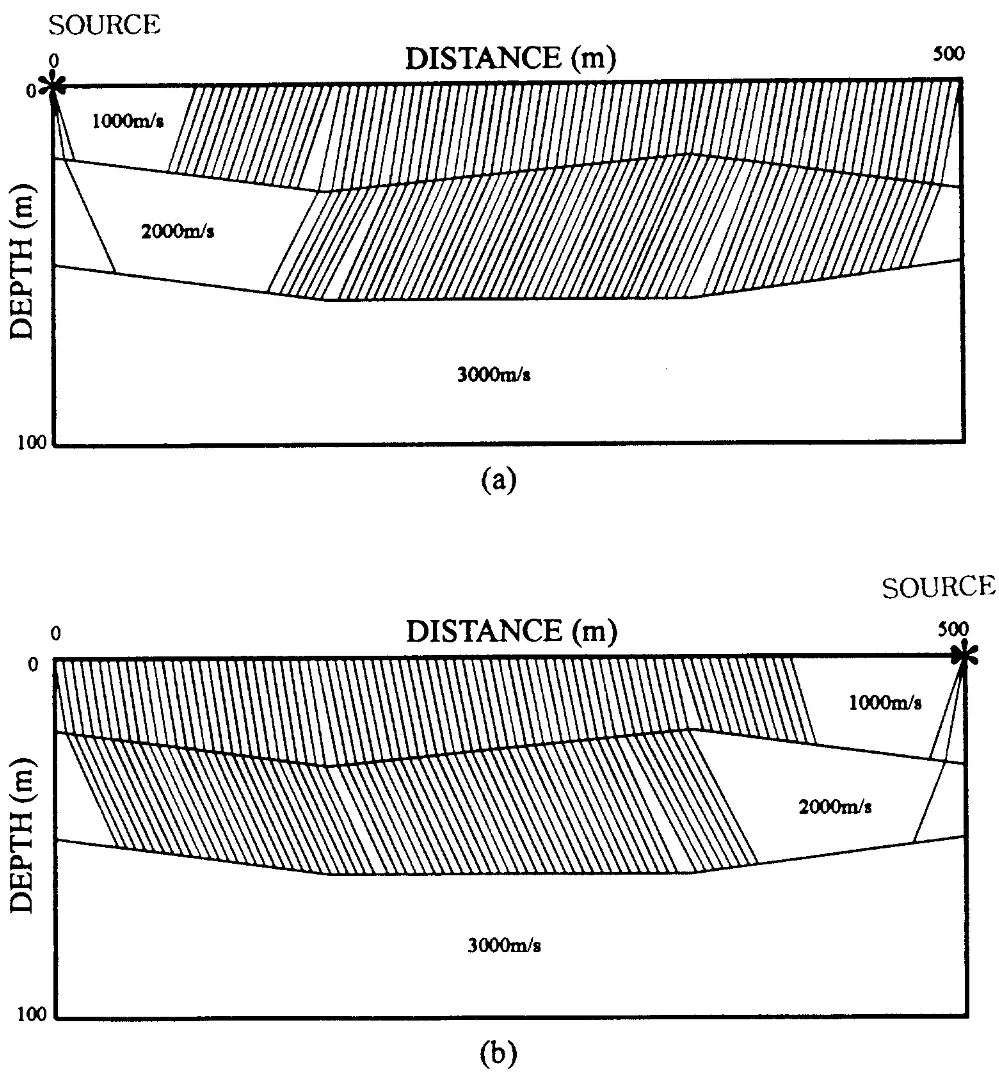

Fig. 2. Diagram of raypaths. Source is located at (a) 0m, (b)500m.

3. Examples

Figure 3(a) shows a curved layer model with an irregular surface. Input data consisting of six shot records are used into the seismic inversion. One hundred receivers are located at a three meter interval. As a initial starting model, two horizontal layers are taken, as shown in Figure 3(b). The unknown parameters for each layer are the velocity and the nine interface coordinates. After the 31st iteration, the velocity and depth model has converged to the true model. Figure 3(c) shows the inverted interface of the model. FIgure 4 shows traveltime curve of synthetic seismogram provided by AMOCO production company. Figure 5 shows the inversion result for Figure 4.

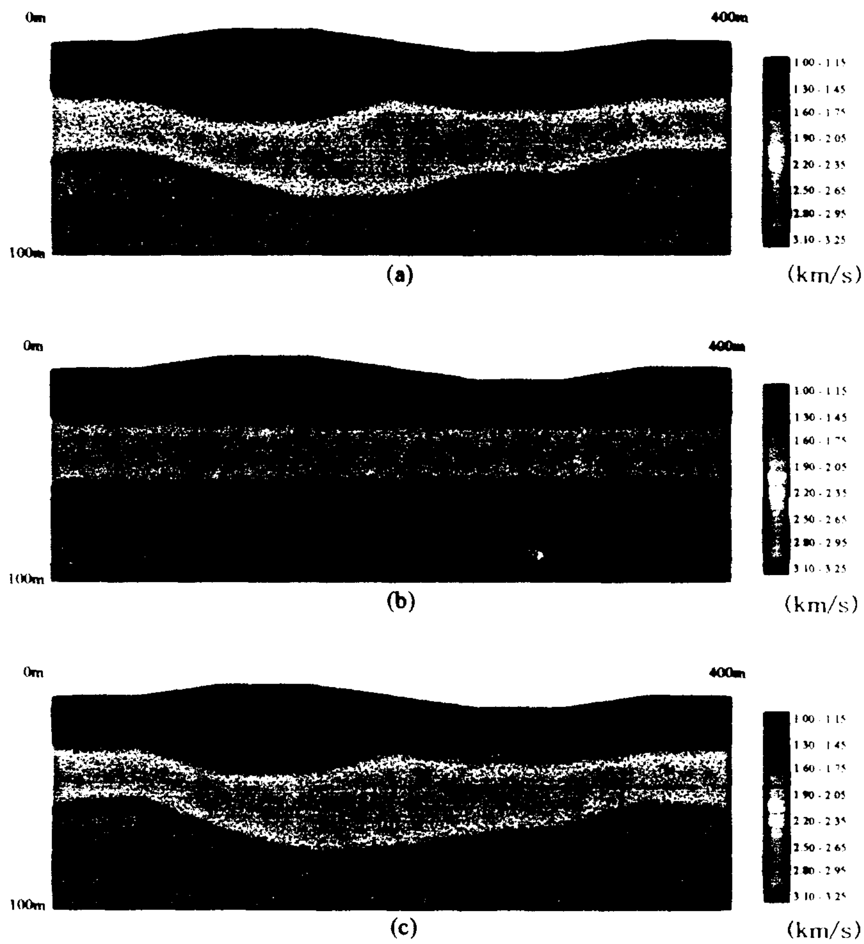

Fig. 3. A three-layered model with irregular surface boundaries and its inverted result. (a) The true model (B) the initial model and (c) the final inverted model.

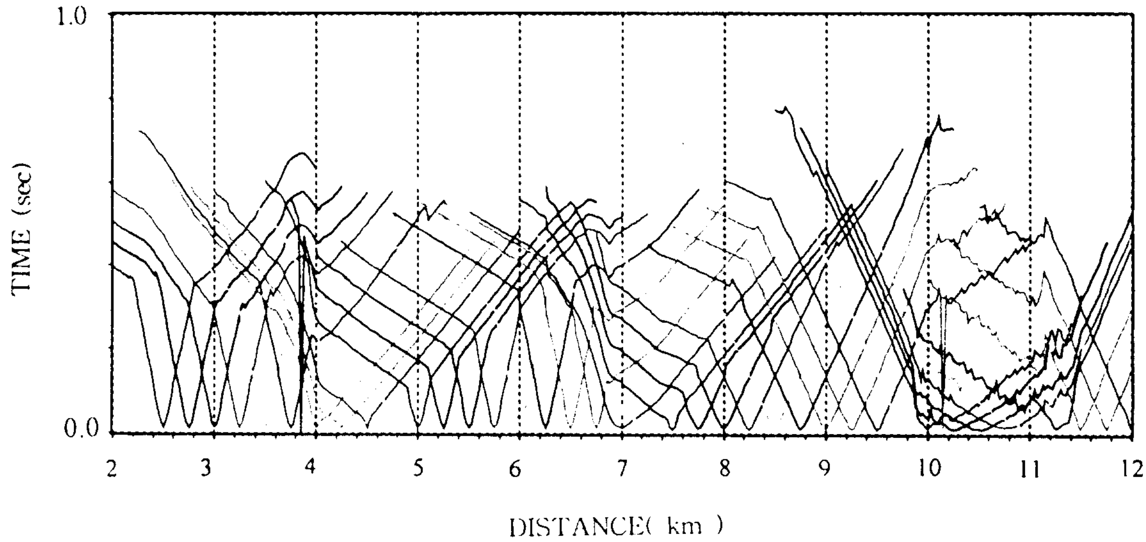

Fig. 4. Travel time curve of synthetic seismogram.

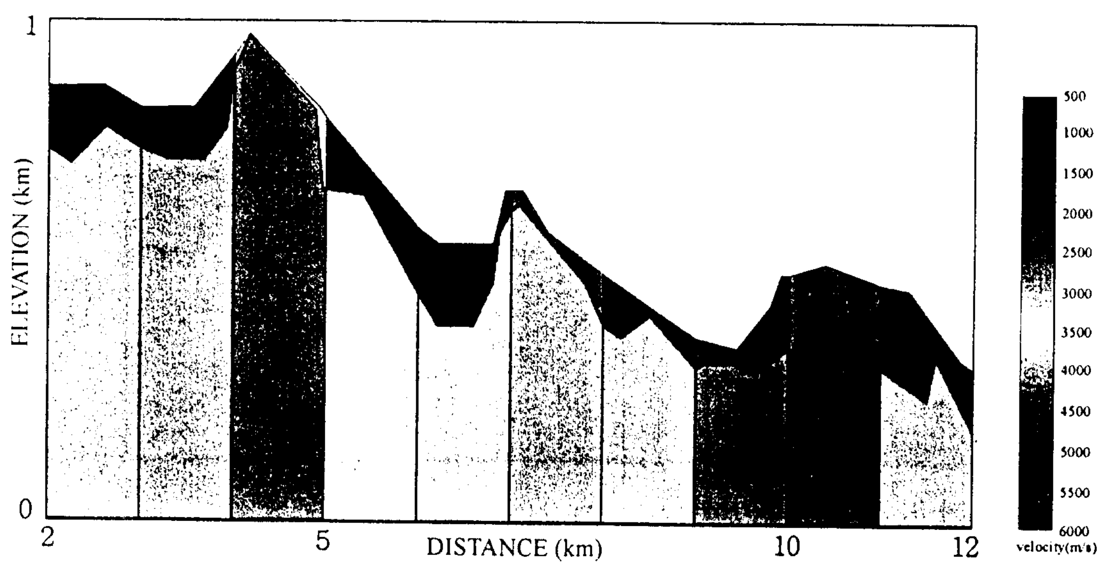

Fig. 5. The model obtained by pseudo waveform inversion.

4. Conclusions

In this paper, we have proposed a new tomographic method for the determination of the velocity-depth model using seismic refraction data.

One of the advantages over other methods is that, unlike the traveltime inversion, the inversion technique can be performed in the frequency domain using the damped Gauss Newton method. Also, we can reduce the traveltime picking procedure by rough picking and muting the refraction data.

The proposed algorithm can be easily applied to real seismic refraction data. Not only can we use low frequency data when the initial model is far from the true model, but we can also refine the resolution limit by increasing the frequency band of the seismic data.

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