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PROPAGATION CHARACTERISTICS OF SEISMIC WAVES BY USING THE THREE-DIMENSIONAL PSEUDOSPECTRAL METHOD

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ABSTRACT

A pseudospectral method is used to evaluate effects of three-dimensional underground structure on seismic wave propagation. The method uses a spatial numerical grid like a finite difference method to calculate spatial derivatives. The calculation of spatial derivatives in this method is made by the fast Fourier transform instead of finite difference. The scheme requires fewer grid points than that of the finite difference method for the same accuracy. The method is therefore more efficient than the finite difference method especially for three-dimensional simulation. The method is applied to the three-dimensional simulation of seismic wave propagation in Ashigara Valley, Japan. Results for the valley subjected to incident Love waves illustrate the variation of the wave propagation direction. The three-dimensional topography of the layer boundaries remarkably affected the Love wave propagation. We will apply this method to the simulation of Hyogoken-nambu Earthquake of Jan. 17, 1995.

KEYWORDS

Seismic wave propagation; three-dimensional simulation; pseudospectral method

INTRODUCTION

Seismic ground motion varies with the one-dimensional (vertical) underground condition beneath the site. Two- or three-dimensional underground structure also affects the spatial variation of seismic ground motion. The generation and propagation of surface waves and the focusing and defocusing of seismic waves are caused by the effects of 2D or 3D underground structure.

Higashi and Kudo (1992) found a significant variation in the Love wave propagation path from source to station by analyzing array data obtained in Ashigara Valley, Japan. They concluded that the three-dimensional underground structure beneath the valley probably caused the variation of propagation path.

In this study, we will investigate the effects of three-dimensional underground structure on seismic ground motion by using the pseudospectral method.

THREE-DIMENSIONAL PSEUDOSPECTRAL METHOD

Theory

A pseudospectral method is a discrete numerical solution method like the finite difference method (FDM). These methods discretize the model and differential operators in space and time, and obtain the solution by solving elastodynamic equations. The difference between the pseudospectral method and the finite difference method is the technique for performing spatial differentiation. The fast Fourier transform algorithm is used to perform spatial differentiation in the pseudospectral method, while a finite difference approximation is used in the FDM.

The most advantage of the pseudospectral method over the FDM is the accuracy of the spatial derivatives for sufficiently band-limited functions. The pseudospectral method requires as little as one-sixteenth the number of grid points per wavelength the second-order FDM does. Thus, the pseudospectral method may reduce computing time and memories compared to FDM for the three-dimensional modeling.

Because of FFT in the spatial differential operation, spatial periodicity is implicit in the pseudospectral method. The model is infinitely periodic as the Aki and Larner method, and the numerical solution is contaminated by wraparound events. Although Cerjan *et al.* (1985) proposed a nonreflecting boundary condition based on gradual reduction of the amplitudes, it is not efficient for seismic waves of long period (5 sec) concerned this study. We used a mapping method (Furumura, 1991) to take artificial boundaries far enough to delay the wraparound and artificial reflections longer than the range of times involved in the modeling.

3D MODEL

Higashi and Kudo (1992) found a significant variation in the propagating direction of Love waves at a period of 5 sec in Ashigara Valley, Japan (Fig. 1). The Love waves incident on the south of the valley turned to a more easterly propagation path and were amplified in the valley. Higashi and Kudo (1992) concluded that it was caused by the three-dimensional underground structure beneath the valley.

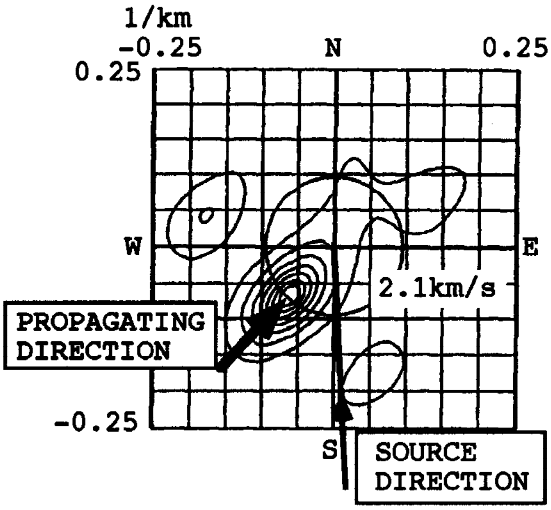

Fig. 1. Frequency-wavenumber spectrum of Love waves at a period of 5 sec in Ashigara Valley for 20 Feb. 1990 Izu-Oshima Kinkai event.

We investigated the variation of the propagating path of the Love waves of 5 sec by the three-dimensional modeling in the area. Figure 2 shows the inclined three-layered model beneath Ashigara Valley area. The top of the model corresponds to the ground level and the bottom is assumed to be flat layer boundary at the depth of 3.3 km.

From the several seismic explosion experiments carried out in this area, P-wave velocities of the three layers were determined to be 3.0 km/sec, 4.2 km/sec, and 5.5 km/sec, respectively. The depth of the upper boundary of the layer of 4.2 km/sec varies 0.7 km in the southwest side to 2.0 km in the northeast side. S-wave velocity and density of each layer were assumed from the model for Love wave dispersion. Table 1 shows the geophysical properties of the model.

The calculation used a 64 × 64 × 32 grid with a grid size dx = dy = 1 km and dz = 0.5 km and a time step size of 0.05 sec.

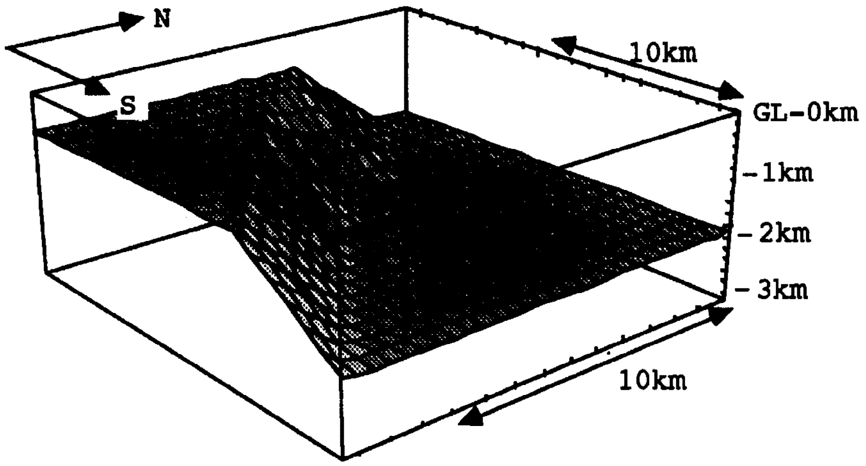

Fig. 2. Three-dimensional inclined model beneath Ashigara Valley.

Table 1. Physical properties of the 3D model

No. of layer	P-wave velocity (km/sec)	S-wave velocity (km/sec)	Density (g/cm^3)
1	3.0	1.5	2.3
2	4.2	2.4	2.5
3	5.5	2.8	2.8

RESULTS AND DISCUSSION

The calculation was carried out on a SUN SPARCstation 10 / M40 (109.5 MIPS, 22.4 MFLOPS) and resulted in elapsed time of 5 hours for 500 time steps.

Figures 3a and 3b present amplitude snapshots of the ground motion as surface plots. Ricker wavelet with a predominant period of 5 sec was incident on the south and the east of the model, respectively, as a plane Love wave. Shape of the wave front varies at the inclined region. Figure 4 shows the dispersion curves of the fundamental mode of

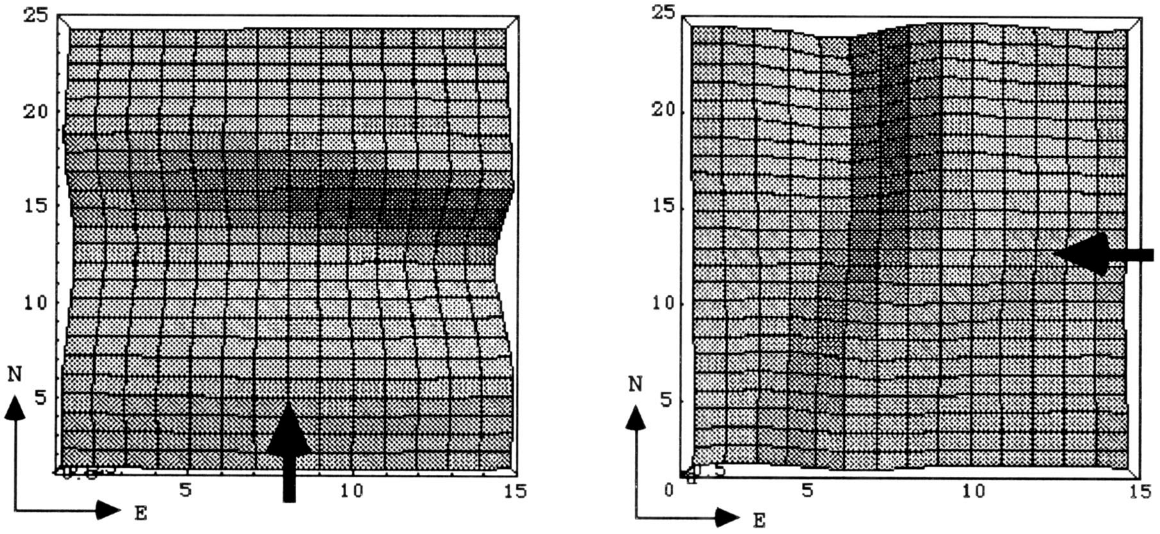

Fig. 3. Snapshots of the ground motion.

a. Ricker wavelet is incident on the south of the model.

b. Ricker wavelet is incident on the east of the model.

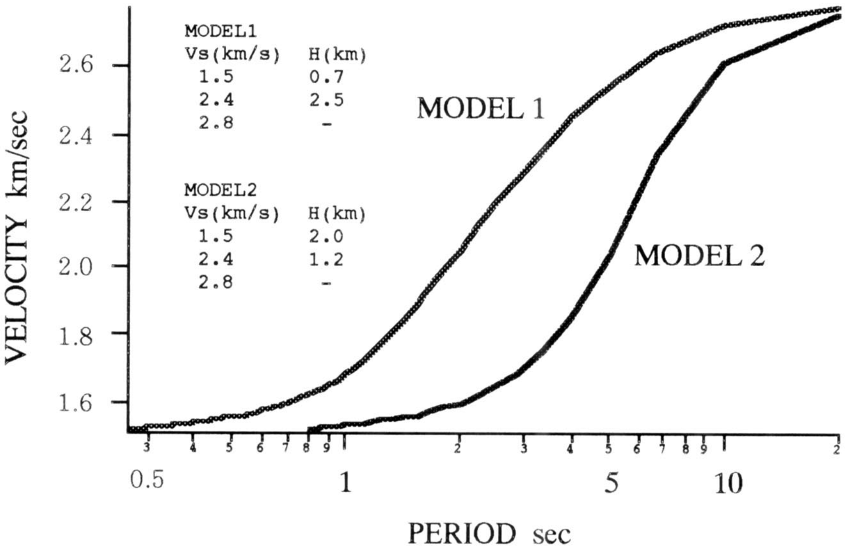

Fig. 4. Dispersion curves of the fundamental mode of Love waves.

Love waves. MODEL1 and MODEL2 are the 1D model of the southwest part and the northeast part of the 3D model, respectively. The first layer (Vs = 1.5 km/sec) of MODEL2 is thicker than that of MODEL1. The difference between the phase velocity of MODEL1 and that of MODEL2 is great at the period of 2 to 6 sec. Thus, it is expected that the propagating direction of Love waves varies in the region because of the great difference in the phase velocity.

Variation of the propagating direction of seismic waves causes the focusing and defocusing problem. Locality of seismic damages occurred in the January 17, 1995 Hyogoken-nambu earthquake may partly result from the focusing of seismic waves. The author will carry out three-dimensional simulations of elastic waves in Osaka Basin to investigate the effects of the underground structure on seismic wave propagation.

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