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DISPERSION OF RAYLEIGH WAVES IN THE KOREAN PENINSULA

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한반도의 레일리파 분산에 대한 연구

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Abstract : The crustal structure of Korean Peninsula is investigated by analyzing phase velocity dispersion data of Rayleigh wave. Earthquakes recorded by three component seismographs during 1999 - 2004 in South Korea are used in this study. The fundamental mode signals of Rayleigh waves are obtained from vertical components of seismograms by multiple filter technique method and phase match filter method. Velocity dispersion curves of surface waves for 14 propagation paths on the great circle are computed from the fundamental mode signals on the great circle path by two-station method. Treating the shear velocity of each layer as an independent parameter, phase velocities of Rayleigh wave are inverted. The result models are regarded as average structure for surface wave propagation paths respectively. All the results can be explained by an earth model of the Korean Peninsula comprising crust of shear-wave velocity increasing from 2.8 to 3.25 km/sec from top to 33 km depth and uppermost mantle of shear-wave velocity between 4.55 and 4.67 km/sec.

Keywords : crustal structure, phase velocity dispersion, Rayleigh wave, multiple filter technique method, phase match filter method, great circle path, fundamental mode

요약 : 본 연구에서는 표면파 분산 분석을 이용하여 한반도에 설치된 광대역 관측소 사이의 지각 및 상부맨틀의 지진파 속도 구조를 연구하였다. 표면파 분산 분석의 two station method를 사용하여 관측소 사이의 지진파 속도구조를 구하였다. 표면파 분산 분석에서 레일리파의 기본모드 신호를 분리하기 위하여 MFT(multiple filter technique) 방법과 PMF(phase match filter) 방법을 이용하였다. Two station method에 의해 두 관측소 사이의 표면파 위상속도 분산곡선을 계산하였으며, 모든 지진원에 대하여 각

경로의 표면파 위상속도 분산곡선을 중합하여 역산에 사용하였다. 역산 결과 각 관측소 사이 경로에서 중합 표면파 분산곡선에 가장 잘 부합되는 지진파 속도 구조를 얻었다. 표면파 위상속도 분산곡선 역산 결과, 두 관측소 사이 표면파 진행 경로의 평균적인 지구구조로서 총 14 개의 관측소 사이의 S파 속도구조를 구하였다. 모든 지구구조는 지표로부터 33 km 까지 약 2.8-3.25 km/s의 속도의 지각과 33 km 이후 약 4.55-4.67km/s의 속도의 상부 맨틀로 구성된다.
주요어 : 지각구조, 위상속도분산, 레일리파, MFT 방법, PMF 방법, 표면파의 진행경로, 기본모드

1. INTRODUCTION

Surface-wave group and phase velocities have provided important information on the properties of the crust and upper mantle in various regions of the Earth (Bonner *et al.*, 2003; Zhou *et al.*, 2004; Morikawa *et al.*, 2004). Their usefulness is partly due to their sensitivity to shear-wave structure; thus, they can provide information which is often difficult to obtain from body-wave studies. Another advantage is that no special assumptions or procedures are necessary to invert surface-wave data for models which include low-velocity zones.

Surface waves are most useful for studying structure in regions that are devoid of large-scale lateral property changes. Implicit in the horizontal-layering constraint *in the surface-wave studies is the assumption that lateral variation of the earth* structure is negligible when compared with its vertical variation.

In this study, the crustal structures of Korean Peninsula are investigated with Rayleigh wave phase velocity data by two station method. MFT(multiple filter technique) method and PMF(phase match filter) method are applied to obtain the fundamental mode signals of Rayleigh waves. These techniques have been used widely and provide a sufficient number of group velocities to construct a continuous dispersion curve in an appropriate period interval from any dispersive wave train. The technique is important for separation of various modes and especially needed when these modes appear simultaneously. MFT is shown to be a fast and efficient means of studying multi-mode dispersed signals (Herrmann, 1973). The phase velocity dispersion curves of the fundamental-mode signals are inverted in this analysis.

2. DATA

Our data are obtained from many earthquakes recorded during 1999 - 2004 at broad band stations in South Korea. Figure 1 show all the broad band stations in South Korea. These stations have been operated by Korea Institute of Geoscience and Mineral Resources (KIGAM) and Korea Meteorological Administration (KMA) and equipped with STS-2, broadband three-components seismic sensor. The seismograms are relatively free of noise. Rayleigh wave data are obtained in vertical components of seismograms. The vertical components of seismograms comprise body waves, the fundamental mode and higher modes of Rayleigh waves and other noises. The fundamental mode signals of Rayleigh waves can be separated by MFT(multiple filter technique) method and PMF(phase match filter) method.

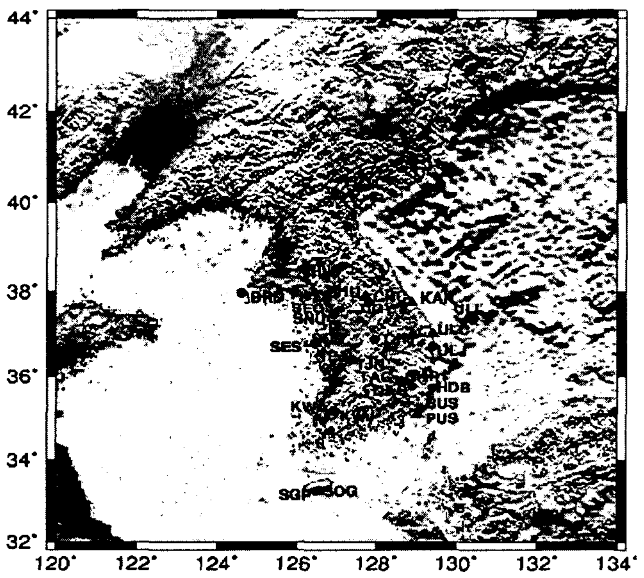

Figure 1. Locations of all broad band stations in South Korea

3. METHODS

1) Two station method

Typically, phase velocity is measured by taking the Fourier transform of a seismogram and obtaining the phase spectrum. The most accurate procedure for estimating phase velocity is to take the difference in the phase spectra at two points on a great-circle path. Phase velocity is given as equation (1) in the two station method.

$$c = \frac{\delta x}{[\delta t_0 + (\delta\phi_H - \delta\phi - 2\pi\delta N)/\omega]} \tag{1}$$

The term $\delta\phi(\omega)$ is composed of two parts, one due to phase variation in the source the other due to the phase response of the recording instrumentation. Here the partially unknown term $\delta\phi(\omega)$ cancels out if identical instrumentation is used at two stations on the same azimuth from the source. We try to use station separations and frequencies such that δN is not ambiguous. If δx is larger the 10 wavelengths, one may have difficulty in determining δN. Thus the determination of phase velocity of surface waves between two stations is inherently differential in nature. However, the differencing of phase-delay times (ϕ_H/ω) between two stations necessitates extremely good time data.

2) MFT and PMF method

In MFT method, amplitudes and phases, as functions of period and velocity, are determined from the output of a set of narrow-band digital filters. The amplitudes and phases of signals passed by an array of narrow-band filters can be used to measure group velocity, relative excitation and transmission as functions of period and velocity, lateral refraction, modal vibrations of the surface, and other dispersion parameters associated with a variety of modes recorded by a single station for one event (Figure 2).

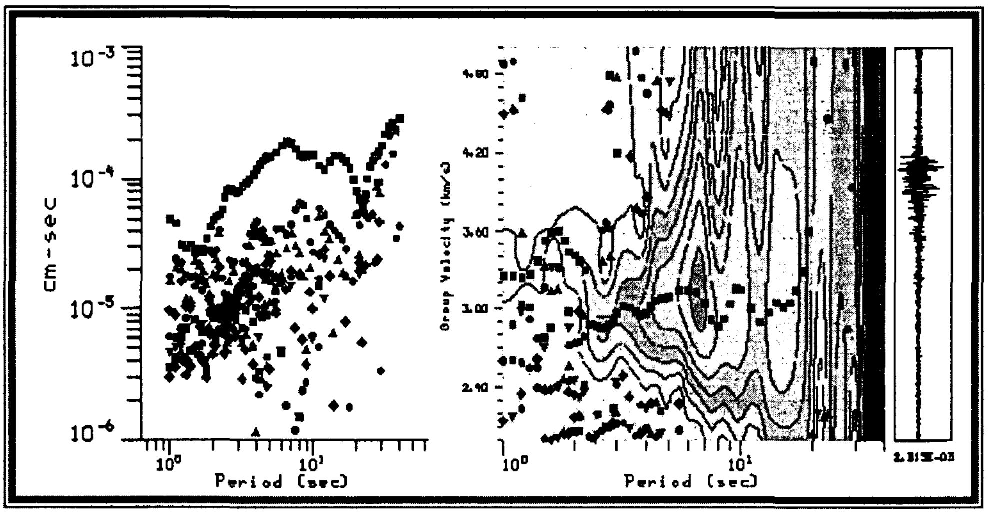

Figure 2. The amplitude (left) and phase (right) spectrums of MFT (Multiple Filter Technique) method.

This technique can recover broader portions of the dispersion present in ordinary recordings, compared to the classical peak and trough method. The technique is also useful when different frequencies of the same mode arrive closely (e.g., surface wave recorded from a near earthquake or surface wave with flat group velocity curve). We can define the mode and then select and separate the dispersion values in a portion of the dispersion plot by PMF(phase match filter) method which requires the specification of a single mode.

4. ANALYSIS

The fundamental mode signals of Rayleigh wave are obtained using the multiple filter technique method and the phase match filter method (Herrmann, 1973). Spectral amplitudes associated with the fundamental mode can be separated from higher modes and noise by the multiple filter technique and the phase match filter method; thus a fundamental−mode signal can be obtained which is not contaminated by higher−mode interference. The fundamental mode signals of Rayleigh wave are obtained from the vertical component of seismograms.

The fundamental mode signals of Rayleigh wave can be classified according to azimuth. Phase velocity data are obtained from the fundamental mode signals of two stations on the same great circle path by two station method. Rayleigh−wave phase velocity dispersion curves of 14 surface waves on the great circle paths are obtained (Figure 3). The scatter in phase velocity dispersion curves can be attributed to several factors, including regional variations in surface−wave velocities, the inclusion of data with low signal−noise ratios, and possible mode misidentification. The Rayleigh−wave phase velocities of all the paths are well consistent with each other for the all period range (Figure 3). This indicates that the earth models under all the 14 surface wave propagation paths are quite similar Rayleigh wave phase velocity dispersion curves for the 14 surface wave propagation paths are used in inversion process. Since good dispersion is shown only for about 10 to 80 seconds, this portion of Rayleigh wave phase velocity data only are used in inversion.

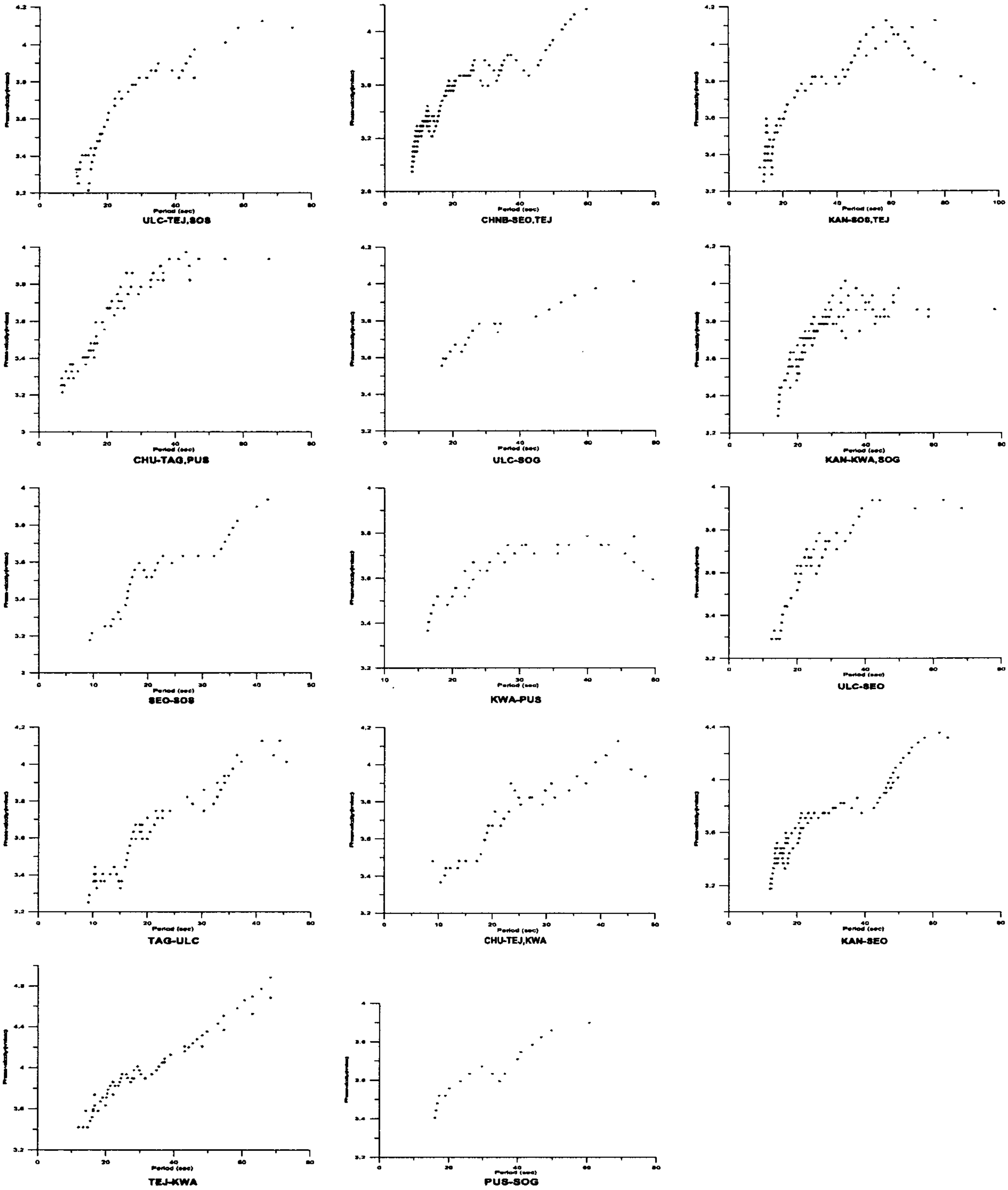

Figure 3. The phase velocity dispersion curves of Rayleigh waves obtained by two station method in the Korean Peninsula.

5. INVERSION RESULTS

The phase velocity dispersion curves are inverted from the initial model, the TJN model obtained by receiver function analysis (Yoo and Lee, 2001) by the SURF program provided by Prof. Herrmann (Figure 4).

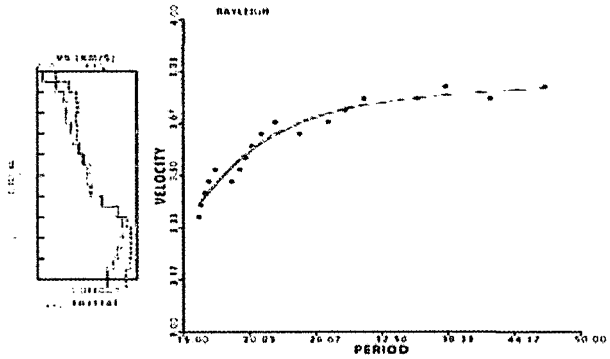

Figure 4. An example of inversion result including the shear−wave velocity structure and the fitting between the observed phase velocity data and the theoretical phase velocity data obtained from the result model. The dotted line indicates initial model.

The earth structures of the 14 surface wave propagation paths are obtained from inversion process (Figure 5).

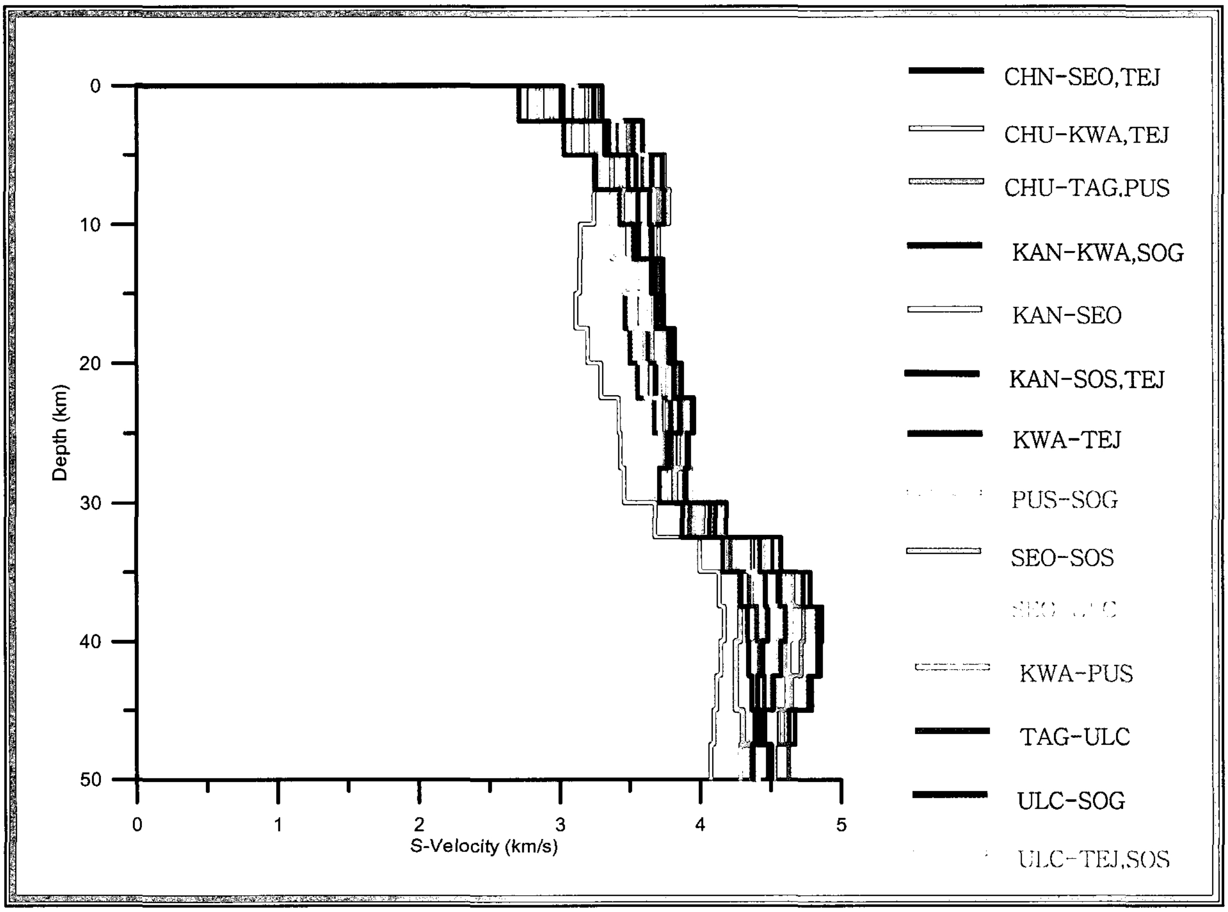

Figure 5. The earth structures of the 14 surface wave propagation paths obtained by two station method

The structure is regard as the average model for the respective path. There is not considerable amount of variation in the result models along various paths. Anyway, the moho discontinuity of 33 km depth seems to be resolved by all the result model. Our shear velocity models for Korean Peninsula are explained by crust with velocity increasing 2.8 to 3.25 km/sec from top to 33 km depth without any significant velocity discontinuity (Lee, 1979) and an upper mantle of average velocity 4.6 km/sec.

6. CONCLUSIONS

Crustal structures for the 14 surface wave propagation paths in the Korean Peninsula are obtained from inversion of the phase velocity data of Rayleigh wave computed by two station method. Our model for Korean Peninsula satisfying all the phase velocity data comprises crust with velocity increasing 2.8 to 3.25 km/sec from top to 33 km depth without any significant velocity discontinuity (Lee, 1979) and an upper mantle of average velocity 4.6 km/sec.

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