MAKARA, SAINS, VOL 9, NO.2, NOPEMBER 2005: 70-74

TOMOGRAPHY S VELOCITY STRUCTURE BETWEEN WASHINGTON'S EARTHQUAKE C022801L AND OBSERVATIONAL STATION TUC THROUGH SEISMOGRAM ANALYSIS

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Abstract

In this research the S speed structure is investigated by seismogram analysis of Washington's earthquake, C022801L using data of TUC station, Tucson, Arizona, U.S.A. The seismogram comparison between the observed and the synthetic seismogram is conducted in time domain and three components simultaneously. The initially input for the calculation of synthetic seismogram is earth model of PREMAN and CMT solution from the earthquake. A low-pass Butterworth filter with corner frequency of 20 mHz is convolved to observed and synthetic seismogram. Waveform comparison shows a real deviation when travel time and waveform of some wave phase are compared, namely on S wave, surface wave of Love and Rayleigh and wave ScS and ScS-2. This research shows, how sensitive the waveform is to the earth model, better than the method of travel time or the dispersion analysis. Research hereinafter is addressed to finish the found discrepancies at S wave, surface wave of Love and Rayleigh and ScS and ScS-2 wave, in observation station TUC. To obtain the seismogram fitting, correction for S speed structure in earth model is needed, that are changes of earth crust thickness, the speed model of β in upper mantle covering the speed gradient of β_h and value of zeroeth order coefficient for the β_h and β_v, for accomplishing the discrepancies at surface wave of Love and Rayleigh. Further correction on S speed is conducted to accomplish the deviation at S wave at earth layering systems from Upper Mantle up to a 630 km depth. Mean while for the ScS and ScS-2 wave phase the correction is carried out on S speed in the earth layers up to CMB. Fitting Seismogram is obtained at waveform of various wave phases that is S wave, surface wave of Love and Rayleigh and ScS, ScS-2 wave, either on travel time or especially also at oscillation number in Love wave. This result indicates that the anisotropy is occurred not only in upper mantle but till deeper earth layers, till CMB.

Keywords: Waveform, S speed in Upper Mantle--CMB, Moho Depth

1. Introduction

A Washington earthquake, coded as C022801L, is a strong earthquake of 6,5 Richter scale, occurred on February 28, 2001. Such a great earthquake as this, the overall earth content is put into vibration. Thereby, all places on the earth surface can sense the ground movement due to the earthquake. Using a sensitive seismometer can the ground movement be measured. The ground displacement is in dimension of [mm/s, mm/s^2] changed to voltage time series by the seismic equipment, recorded and redisplayed as a seismogram. Seismogram consists of wave phases that the wave by the propagation overcomes some reflection or refraction in the earth layer system, which results overlapped waveforms in the seismogram.

Quantitative analysis performed on seismogram time series is to measure the travel time, polarity of the P and S wave, and the relation of the phase or group velocity to the periods, so called the dispersion analysis. The easiest measurement is the travel time of P wave, because it is the first break.

From notes of travel times data can some descriptions about global earth model like SPREM [1], IASPEI91 [2] and AK135 [3] or regional earth model with finer resolution, description about earthquake, the hypocenter, the time origin and quake mechanism be derived.

The amount of travel time data performed by hundreds couples of hypocenter -observation stations from thousands earthquake during years can reach millions. But the main part consists of P travel times, because of easiest travel time measurement by the first break in seismogram. The S measuring is not so easy, because S wave contains lower frequency and lies in the overlapped and complex wave phases.

The global earth models like IASPEI91, SPREM and PREMAN (anisotropic version of SPREM) and many regional earth models that derived from these global earth models are main, obtained from the travel time data. The elastic parameter yielded from travel time data are only P and S speed structure, where the P speed structure is more accurate determined than the S speed structure, due to scarcely S travel time data [1]. The other elastic parameter of the earth structure, like mass density, quality factor of μ and κ and anisotropy are obtained by using the dispersion analysis on the surface wave that is executed on three component separately. The data used in the dispersion analysis is indirect.

Both quantitative methods used to analyze the seismogram evaluate only few and certain information relied in the seismogram. There are many seismological researches [4-6] about earth model with finer resolution, where the data are still the travel time and dispersion analysis on surfaces wave.

Research in this paper used the seismogram comparison between the observed and its synthetic in time domain and three components simultaneously, where the overall information relied in the seismogram will be analyzed. Question raised in this research is, whether the obtained earth models using few and certain information can give back a synthetic seismogram, that is likely as the observed seismogram, though the seismogram comparison is conducted with corner frequency of 20 mHz [7].

The synthetic seismogram is calculated using GEMINI program [8,9], whose input is a complete elastic earth model, a CMT solution from the earthquake and the geographical location of the observational station. To compare the seismogram in the same dimension, that is mm/dt, the response file of the station is then convolved to the observed seismogram. The seismogram data is the property of Incorporated Research Institutions for Seismology (IRIS) and downloaded using HTTP.

2. Method

Seismogram data can be obtained from IRIS databank center. Earthquake excites ground movement, where this movement is recorded in three directions of cartesian components (N-S, E-W, and vertical) local in the observational station. The recording is labeled with the suffix of -E, -N and -Z. The geographical location of the earthquake's epicenter is 47.15^0 North Latitude and 122.73^0 West Longitude, whereas the observational station TUC is 32.31^0 North Longitude and 110.78^0 West Longitude. To decompose the ground movement into directions of toroidal and vertical-radial must the horizontal plane performed by the N-S and E-W components be rotated, in such a way that the angle is formed between the local North and the direction from the TUC station to the epicenter (back-azimuth), as illustrated in Figure 1. Rotation is needed to decompose the 3 - dimensional movement into wave propagation of P-SV and Rayleigh, SH and Love.

First a computer program must be run to calculate the travel time used to identify the wave in the seismogram that is TTIMES program, which based on article from Bulland and Chapman [10], which obtained from http://orfeus.knmi.nl. To produce a complete synthetic seismogram from an earth model with a certainly hypocenter depth, we use a computer program based on the GEMINI (Green's function of the Earth by MINor Integration) method. Before running the program the input must be prepared, consists of an earth model, a hypocenter depth, the CMT solution of the earthquake, and the location of the TUC station. As an input, the earth model should have complete elastic parameter that is earth layer system, P and S velocity structure, mass density of the rock constituted the earth model, quality factor of μ and κ and the vertical anisotropy in the earth layers.

The GEMINI method is equivalent to the summation mode, but the frequency can be set arbitrary and produces a complete synthetic seismogram in time domain and three cartesian components. GEMINI program calculate the minors of the Green's function

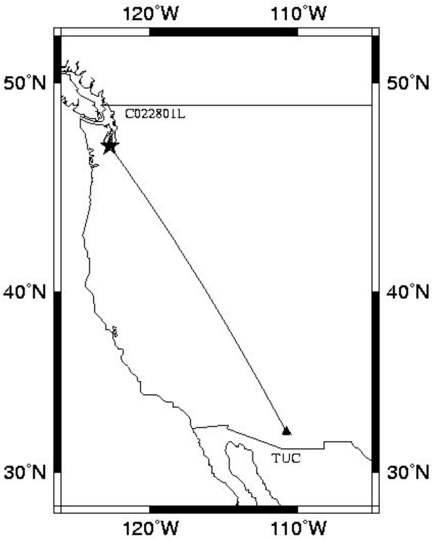

Figure 1. Vertical projection of wave propagation way from C022801L earthquake epicenter to observation station TUC

from an earthquake with a certainly hypocenter depth. The Green's function must fulfill the boundary conditions in the earth surface, hypocenter depth and the deepest point in the wave propagation. The Green's function is expanded where the independent variable is complex frequency, by introducing an imaginary positive constant to the real frequency. This trick is to avoid the time aliasing.

DISPEC program (included in GEMINI program) reads the location of the observational stations and moment tensor parameter, which is written in the third line of the CMT solution [11]. The epicenter coordinate and the station's coordinates are transformed, so that the epicenter acts as *North Pole*, and the epicentral distances and azimuth angles of the observational stations are determined. The spherical harmonics are expanded using these values. The DISPEC reads the minors of the Green's function that produced by the GEMINI program and performs multiplication and summation to the spherical harmonics and transforms back to original geographical positions. The synthetic seismogram is obtained, but still in complex time domain.

The MONPR program (included in the GEMINI program) transforms back to real frequency and inverse transform to time domain. The response file of the station is subjected to the observed seismogram, so that seismogram comparison between the real and synthetic ones is conducted in the same dimension.

The data amount by seismogram comparison in time domain and three components simultaneously is thousands, the changes in earth crust thickness (Moho depth), S velocity structure in the upper mantle and layers below is conducted through a trial - error method.

3. Results and Discussion

In this article, the analysis of the Washington, U.S.A earthquake, coded as C022801L, be presented, where the data are recorded in observational station TUC, Tucson, Arizona, U.S.A. The seismogram analysis is executed after imposing a low-pass filter with corner frequency of 20 mHz [12].

Figure 2 shows a seismogram comparison between the data and the synthetic, which is calculated from corrected earth model and augmented with ones from PREMAN model.

Seismogram analysis and fitting in observational station TUC is presented in Figure 2. This figure shows seismogram comparison between the data and the synthetic from PREMAN and corrected earth model in time window from S wave, surface wave of Love and Rayleigh till the ScS & ScS-2 wave. The epicentral distance of the TUC station is 17.3^0, short enough, so that the S waveform lies in the start phase of Love wave oscillations. Therefore, the measurement of S travel time in the oscillatory motion of surface wave is not easy.

The aim of this research is to correct the met discrepancies, initially is to fit the surface wave of Love and Rayleigh. The surface wave propagates along the earth surface and penetrates into the earth, whose penetration depth is equal to the wavelength of the surface wave [13]. Perception is, that Love waveform from PREMAN has three maximums, and they arrive early than the real Love waveform. Fitting on Love wave is obtained by changing the Moho depth become 34 km and SH wave speed gradient (β_h) in the upper mantle become positive. Compare to a negative gradient in the PREMAN model.

The correction on the zero order coefficient of S velocity function in the upper mantle must take a negative value, because the Love wave from PREMAN arrives early than the real Love. Mean while, the perception shows that synthetic Rayleigh waveform from PREMAN on r and z components arrives 35 seconds early than the real Rayleigh. This advance is too big for a short epicentral distance. Therefore, correction must be executed on β_V in the upper layer and takes a negative value, so that the fitting on the Rayleigh wave is obtained.

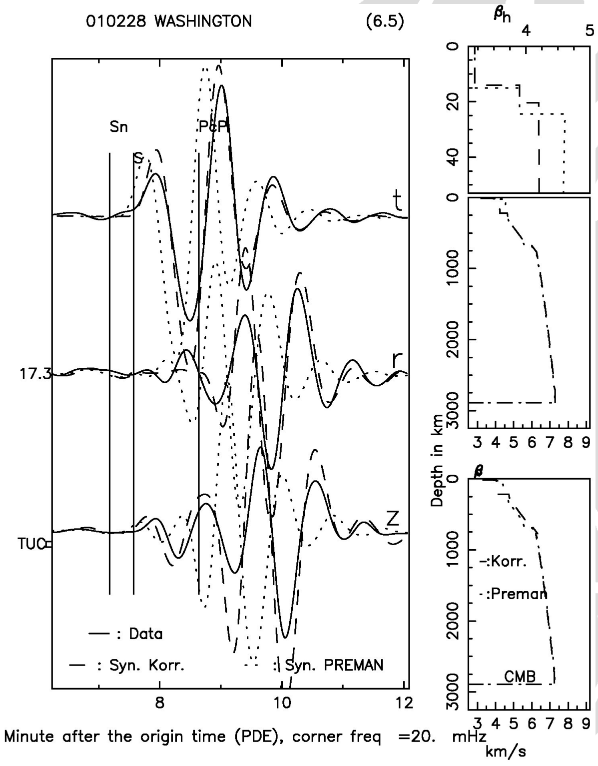

Figure 2. Seismogram comparison between real and synthetic from corrected and PREMAN earth model in the station TUC in time windows of a. S, L and R wave b. ScS wave.

To fit the S body wave, correction to the velocity structure in the earth layers below the upper mantle down to depth of 630 km must be taken into account. The synthetic SH from PREMAN arrives early than the real SH. The synthetic S and Rayleigh waveform from PREMAN has shorter period than the data. The corrections on the earth layers from the upper mantle down to a depth of 630 km bring repairs on S wave comparison. We can see that the fitting goes from the SH and SV waveform till the end of surface wave of Love and Rayleigh waveform.

The S velocity structure in the upper 630 km has been corrected with negative values. These negative corrections have consequence to travel time of ScS wave. This wave is a depth phase that propagates from hypocenter nearly vertical downward until met the CMB interface, and back reflected to the earth surface. Because the S velocity structure in the upper 630 km has been corrected with negative values, the correction on S velocity structure in the base mantle is with positive values carried out, to fit the ScS waveform. The fitting is also achieved on the ScS repetitive, namely ScS-2 (Figure 3). The epicentral distance is 17.3^0, a short distance, but this waveform method gives a new analysis method. Compare it to other seismological research [14 – 16] that tried to interpret the S velocity structure in the base mantle using differential travel times of phases SKKS and S, where they need observational stations whose their distance is greater than 83^0.

From the figures we can conclude that waveform analysis on observational stations with so small epicentral distance can give knowledge about the velocity structure in the base mantle. Another aspect is that the effect of earth crust thickness (Moho depth) to the amplitude height on the Love waveform is not yet benefit on the determination of the CMT solution [11].

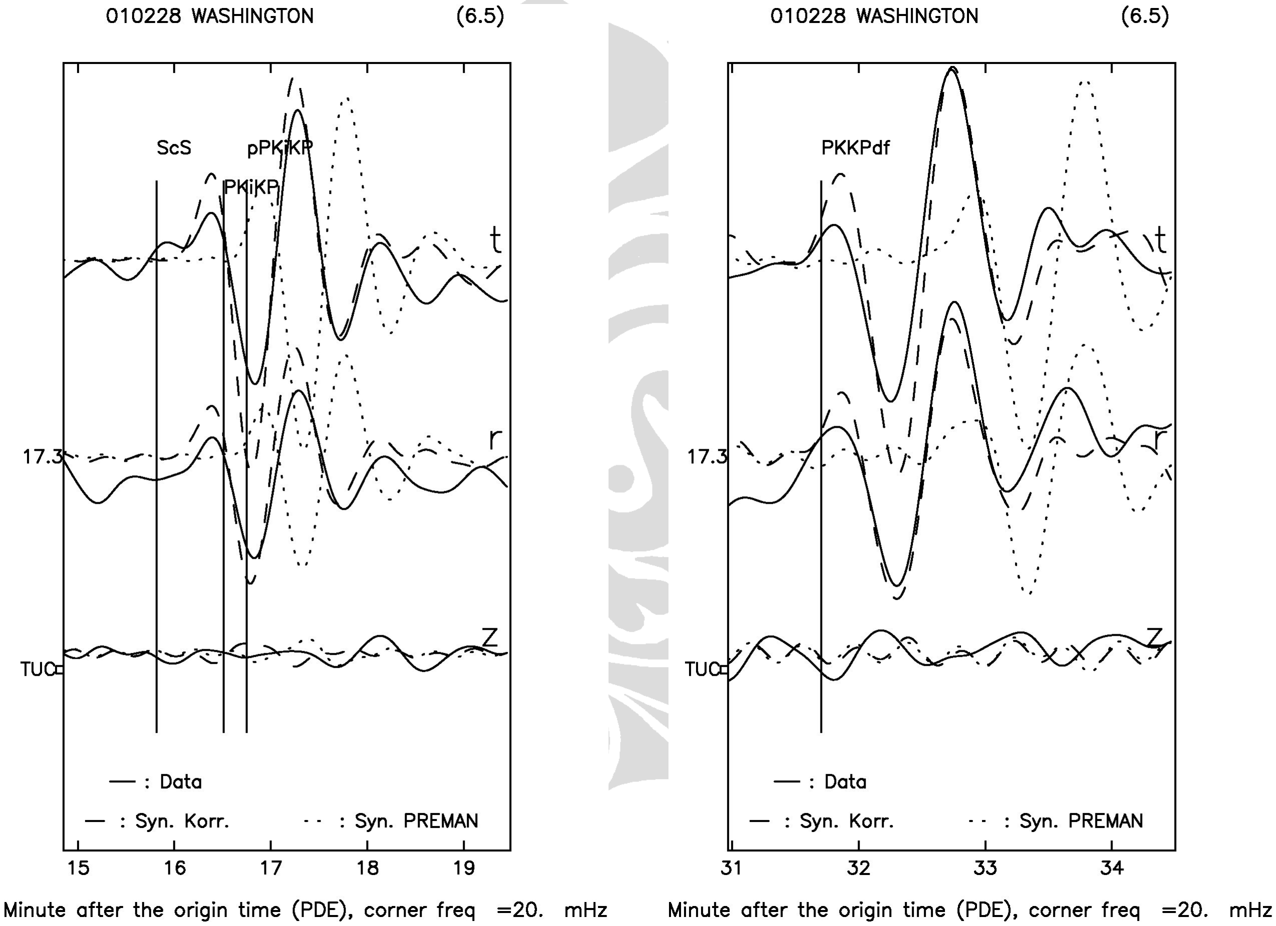

Figure 3. **Seismogram comparison between real and synthetic from corrected and PREMAN earth model in the station TUC in time windows of ScS-2 wave**

4. Conclusion

Seismogram comparison between data and synthetic in TUC station show a big discrepancy neither the travel time nor the waveform of some various wave phases, namely from S wave, surface wave of Love and Rayleigh and ScS and ScS-2 wave. The result shows how the sensitive of the waveform to the earth model. The obtained fitting in Love wave is either in travel time or amount of oscillation, or the travel time in Rayleigh wave, that is very excellent. The fitting from S wave, surface wave of Love and Rayleigh and ScS and ScS-2 wave is excellent. The result shows that the 1-D S velocity structure between hypocenter and observational station TUC is unique. The Love waveform reacts significantly to the Moho depth, although the frequency corner is set at 20 mHz. The vertical anisotropy lies not only in the upper mantle but also on deeper layers till CMB.

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