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SEISMOGRAM CONSTRUCTION TO FIT THE RECORDED B032593C EARTHQUAKE, JAPAN ON OBSERVATION STATION BFO, GERMANY

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Abstract

In this research the model of earth layers between earthquake's epicenter in Hokkaido Japan and observation station in Black Forest of Observatory (BFO), Germany is investigated. The earth model is 1-D that represents the average speed model. The earth model is obtained by seismogram comparison between data and synthetic seismogram in time domain and three components simultaneously. Synthetic Seismogram is calculated with the Green's function of the Earth by MINor Integration (GEMINI) program, where program's input is initially the earth model IASPEI91, PREMAN and also the Centroid Moment Tensor (CMT) solution of the earthquake. A Butterworth low-pass filter with corner frequency of 20 mHz is imposed to measured and synthetic seismogram. On seismogram comparison we can find unsystematic discrepancies, covering the travel time and waveform of all wave phases, namely on P, S, SS wave and surface wave of Rayleigh and Love. Solution to the above mentioned discrepancies needs correction to the earth structure, that covering the change of earth crust thickness, the gradient of β_h and value of zero order coefficient in β_h and β_v in upper mantle, to get the fitting on the surface wave of Love and Rayleigh. Further correction to accomplish the discrepancies on body waves is conducted on layers beneath upper mantle down to depth of 630 km, where a little change at speed model of P and S wave is carried out. The number of oscillation amount especially on Love wave is influenced by earth crust depth earth. Good fitting is obtained at phase and amplitude of Love wave, but also at amplitude of some body wave too. This effect is not yet been exploited for the determination of moment tensor.

Keywords: seismogram, velocity model from upper mantle – CMB, Waveform

1. Introduction

Earthquake B032593C is a strong earthquake, took place on March 25th, 1993 in Hokkaido Japan with the Richter scale of 5.8. Due this earthquake the entire earth content will be vibrated, so that all place on the earth surface could measure the ground vibration because of the earthquake.

The ground movement is measured through seismometer in receiver station, altered from velocity or acceleration of ground movement in (mm/dt, mm/dt^2) becoming to voltage (mV), recorded as a time series and represented as seismogram. Seismogram consists of complex wave phase coming from reflection or refraction that occurred in the earth.

This shows the existence of parameter elastic difference in the layer systems of the earth model. Wave propagation from source of earthquake to receiver station meets various interfaces, so that seismogram consists of various complicated wave phases.

Quantitative analysis on seismogram is performed by noting the arrival time of wave phases, the highest amplitude of surface wave, polarity of P and S wave, and relation between phase or group velocity and the period or frequency of surface wave, known as method of dispersion analysis, where in this method the measured data is indirect. The easiest observation is to measure the arrival time of P first break.

From a note of arrival times of some wave phase can some descriptions be derived, for example description about earth models like SPREM [1], IASPEI91 [2] and AK135 [3], either a globally earth model or regional earth structure, and description regarding the earthquake source, either hypocenter location, the origin time of earthquake happening or mechanism. While to determine the released energy by the earthquake, the time series in seismogram is evaluated, as explained in determination of CMT solution [4].

From an earth model, by giving the coordinate of two points namely hypocenter and observation station then the travel time of various waves can be calculated. This travel time is used to identify the wave phase in seismogram. Using a time curve & time difference of some wave phases then the epicentral distance from observer station to earthquake source can be determined. From some observation stations that encircle the earthquake source then the location of earthquake epicenter can be reckoned [5].

The amount of travel time data formed by various wave phases from couples of hypocenter, observation stations from thousands earthquake during tens of year can reach millions. Structure of the earth model, like IASPEI91, SPREM and furthermore earth models with the more resolution referred from both standard earth models is determined using this travel time data. Elastic parameters obtained with the travel time are only the wave speed of P and S. Other elastic parameter, for example mass density, quality factors of damping and anisotropy in the earth structure are obtained by using the method of dispersion analysis in surface wave that done per component of ground movement, where the relation between phase or group velocities to periods is searched.

The standard earth models, that often raised as reference model by seismology expert, namely IASPEI91 and PREMAN (anisotropy version of SPREM) can be seen in Figure 1 down to a depth of 1000 km.

Two quantitative methods used to analyze the seismogram above evaluate only a little certain information in a time series in seismogram. There is a lot of research about earth models with the more resolution [6,7] uses still the travel time data and dispersion analysis on surface wave.

Research in this article uses the method of seismogram comparison between data and synthetic in time domain and three Cartesian components simultaneously. The

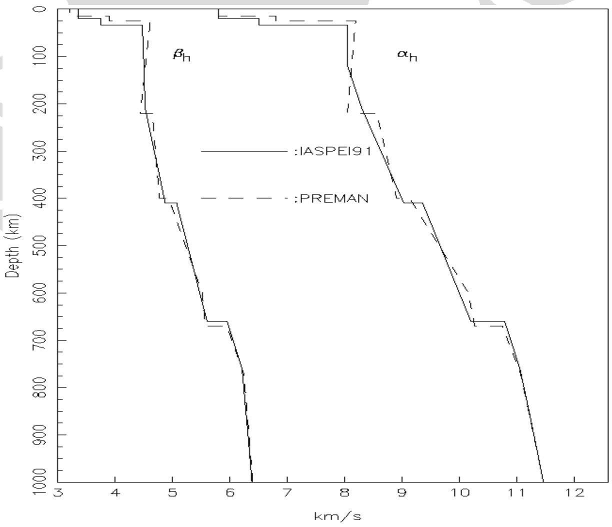


Figure 1. Earth structure from standard earth model, the standard isotropy IASPEI91 [2] and vertical anisotropy PREMAN [1] down to depth of 1000 km

raised question is, whether standard earth models obtained by evaluating a little information in seismogram can give to return the seismogram synthetic, which is like the seismogram observation, although seismogram analysis is carried out with the corner frequency of 20 mHz. It will be compared the overall information which implied in the seismogram through the waveform analysis. This method is the best [5].

Synthetic seismogram is calculated with the GEMINI program [8,9], where the input consists of a complete elastic earth model, the CMT solution from earthquake B032593C and the domicile of the observation station BFO. Utilize to compare the synthetic and real seismogram in a same dimension the file response of BFO station is convolved to the synthetic seismogram. The seismogram data is property of German Regional Seismic Network (GRSN), and downloaded via HTTP.

2. Metode Penelitian

The following consideration will be written down shortly an equation system for ground movement as effect of wave propagation that excited by an earthquake.

These systems represent the mathematical method for the GEMINI program, where the calculation of synthetic seismogram is conducted by solving the equation systems in complex frequency domain.

In general, ground movement is a differential equation systems in time domain, which its derivative to time becomes to lose when transformed to frequency domain

(1)

Because the earth is depicted as a ball, the coordinate system used is spherical coordinate. Strain, divergence of tension and force are expressed as:

(2)

where *U*, *V* and *W* are components of ground movement in vertical, east-west and north-south direction. Earthquake source is suppose located in North Pole, also decomposition for divergence tension (*R*, *S* and *T*) and force vector (*G*, *H*, and *K*), and the surface gradient is

(3)

Hooke's law describes the relation between strain, force and tension. Using the expansion of spherical harmonic function this relation can be written down as

(4)

where *U* is a spherical harmonic coefficient. The wave equation becomes six coupled first order differential equations system.

(5)

Three first components of A vector are the ground movement in spherical coordinates, and the next three are for tension.

Form of the differential equation system for the spheroidal movement is in form of 4x4 system:

MAKARA, SAINS, VOL. 9, NO. 1, APRIL 2005: 19-27

(6)

and system of 2x2 for toroidal movement.

(7)

A, F, C, L, N and ρ are elastic parameters of earth's constitute rock. The laid over quantities tilde notation means that the independent variable is complex frequency. Here we can see, that both elastic parameters *L* and *N* are exist in equation of motion (*V* and *W*). Both these parameters give the major effect at Love and Rayleigh wave. Expansion for spherical harmonic coefficient is also calculated for terms in tensor moment of the earthquake, which forces can be expressed as stress divergence.

(8)

so that expansion of spherical harmonic for forces contains coefficients with the δ function (index 1) and its first derivation to *r* (index 2)

(9)

Because that the solution function is expanded in spherical harmonic functions, later then reinserted into wave equation and its result is in the form of order one differential equation system. In such equation as this, the parameters of solid elastic substance enter at the components of Kernel matrix.

Utilize to include the nature of inelastic earth, the real frequency ω is changed to complex frequency by introducing a small positive imaginer number, notated by σ, becoming ω + iσ. This differential system is later then integrated, one from the middle point of earth core, or from a radius point, where the amplitude of a wave phase in that point has exponentially decayed [8], till to earthquake source depth (notation by g_1 and g_2, others by integration from the earth surface to the source depth (w_1 and w_2). The solution must fullfillen the boundary condition at earth surface that the tension is equal to zero, and also at the interface of solid and fluid, that the tension shifts to disappear. Result of integration, the so-called Green's function is later tapered down and results are then compared to the coefficient of expanded source.

(10)

where ***s*** is the strength of the earthquake whose components are the elements of the CMT solution.

Each amplitude function of spheroidal and toroidal movement is solved by using the Cramer's rule.

(11)

The solution of linear equation with the Cramer's rule_needs the existence of discriminant formed by Green's function values product at source depth has finite values. But at Eigen frequencies the discriminant has null value. Because the weakness of numeric systems, values of Green's functions integration have big order, but the difference between Green's functions product has small values that smaller than the numerically *round-off*.

To overcome this difficulty, the differential equation system is altered into differential minors calculation form. By using matrix coefficient of the homogen systems, we formulate the system differential equation for the minors:

(12)

and

The last equation must be fillfulled by the equation system integration. These differential minors system are later finished with ordinary integration method. Complete description for theory of wave propagation in the earth medium can be found at article [8].

Hence, Green's function amplitude is still in complex frequency. It can be finished for an earth model with the complete parameter elastic, source depth and strength of earthquake. To obtain the synthetic seismogram at an observation station, the station's epicentral distance and azimuth from the earthquake source are given, and from these parameters the spherical harmonic functions are expanded. When the minors are complete calculated, the spherical harmonic functions are summed for that stasion's coordinate. The result is afterwards back Fourier transformed to the time domain.

Seismogram is obtained from databank center GRSN. Each earthquake yields the ground movement, from which a station will be recorded in three directions of Cartesian component (N-S, E-W and vertical Z, local at receiver station ort, known as canal with the suffix -- E -- N and -- Z). The earthquake's epicenter is in Hokkaido, Japan, with the coordinate 41.79^0 latitude North and 143.49^0 longitude East. To dissociate the component of ground movement in direction of toroidal and radial directions, the horizontal area formed by line of local N-S and E-W in observation station have to be turned around, in such a way till the epicenter ware the *North Pole*, this is direction from observation station to earthquake epicenter (back-azimuth), illustrated by Figure 2. Rotation is needed to dissociate the wave propagation in 3-D roomy becoming mode of P-SV and SH wave.

In this research a computer program has to be run to get the travel time of synthetic wave phases, that is TTIMES program, which is based on Bulland and Chapman [10] got which is from http://orfeus.knmi.nl. While to produce the synthetic seismogram from the earthquake in observation station is used a computer program being based on method GEMINI. When this program runs, an earth model shall be given as input, that is first the earth model IASPEI91 and PREMAN. As an earth model, the data has to contain the complete elastic parameter, that is covering propagation speed of compression and shear wave, mass density, quality factor μ and κ and anisotropy from constituent rock of earth structure.

Elastic parameters in the IASPEI91 earth model are not so complete as those contained in the PREMAN earth model. Therefore, the elastic parameters, which are not owned by the IASPEI91, are loaned from PREMAN model.

GEMINI method is a method, which is equivalent to the method of normal mode, where the highest frequency can be arbitrarily selected and yield a complete synthetic seismogram in time domain and three Cartesian components simultaneously. GEMINI (Green's function of the Earth by MINor Integration) program calculates the minors of the Green's function for an earth model and with a certain hypocenter depth,

Figure 2. Wave way from epicenter to observation station BFO

where Green's function is expanded to fulfill the boundary condition in reflection point in wave propagation, in the earthquake's source depth and at earth surface. Expansion is written down in complex frequency, by including trick to avoid the time aliasing. DISPEC Program (including GEMINI package) reads the position of receiver station and parameter of moment tensor, which is described in third line of CMT solution. Geographical positions of epicenter and receiver station are transformed into coordinate system, where the epicenter holds as coordinate center, then epicentral distance and azimuth are calculated and the harmonic spherical functions for all receiver stations are expanded. DISPEC program reads the outputted Green's minors from GEMINI, and form the summation to the harmonic spherical functions and perform the back-transform return to geographical coordinate. The result is synthetic seismogram which still in complex frequency domain. The MONPR program back-transforms the result to synthetic seismogram in time domain. The response file from systems of equipments seismometer is imposed to the synthetic seismogram. On both seismograms the data and synthetic is the Butterworth low-pass filter imposed.

The amount of data in the time domain seismogram comparison with three components is on the order of thousands, hence, a change made on the crust, the speed of the gradient, and the zeroeth order coefficient value in the speed polynomial are conducted through a trial and error method.

3. Results and Discussion

This research presents a seismogram analysis of an earthquake that took place on March 25th, 1993 in Hokkaido, Japan and recorded by observational station BFO, Germany.

Figure 3 shows a seismogram comparison in three components where the synthetic seismograms are calculated from earth model of IASPEI91 and PREMAN. The lower set of picture shows seismogram comparison that reckoned from PREMAN earth model, whereas the upper set is from IASPEI91 earth model. To identify the wave in seismogram we use the travel time of some wave phases that calculated by TTIMES program, constructed from IASPEI91 earth model and based on paper (expressed as vertical line in picture) [10]. A set of picture consists of three traces that the lowest trace presents the vertical component (z) of ground movement, and the middle and the highest present for radial and toroidal and radial component respectively. The abscissa expresses the time in minute after the origin time (according the PDE), whereas the ordinate expresses the amplitude comparison.

Figure 3 shows seismogram comparison for the primary wave phases P and repetitions. In the lower picture we can see that the P synthetic waveform arrives 3 second

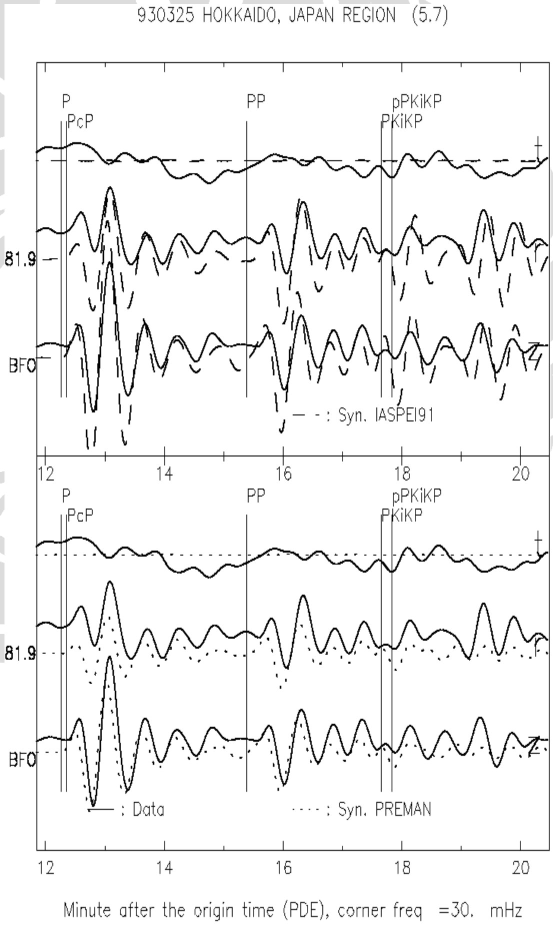


Figure 3. Seismogram comparison and travel time in time windows for P waves, where corner frequency set at 30 mHz

earlier than the real P waveform, whereas the PP synthetic 5 second earlier than the real PP. The IASPEI91 earth model has an earth thickness of 35 km and PREMAN model 25 km, differing only 10 km. With the corner frequency of 25 mHz the wavelength is around 150 km, it is the fact that both model of earth crust thickness give real influence at amplitude height of P body wave [11]. In the upper picture we can see that P and PP synthetic waveform from model IASPEI91 come also earlier than wave of real P and PP.

Figure 4 shows a seismogram comparison in time window of S secondary wave, where corner frequency degraded to 20 mHz. It can be seen, how influence of earth crust thickness to the oscillation amount in S wave. The model of PREMAN owning 10 km thinner earth crust gives the synthetic S wave that has shorter oscillation than the synthetic S from IASPEI91 earth model. It can also be seen that there is a discrepancy in arrival time of S and SS wave phases. The synthetic S and SS waves from PREMAN arrive earlier than real S and SS, whereas IASPEI91 model gives a good fitting that the S wave arrives on time, but the synthetic SS wave arrives later.

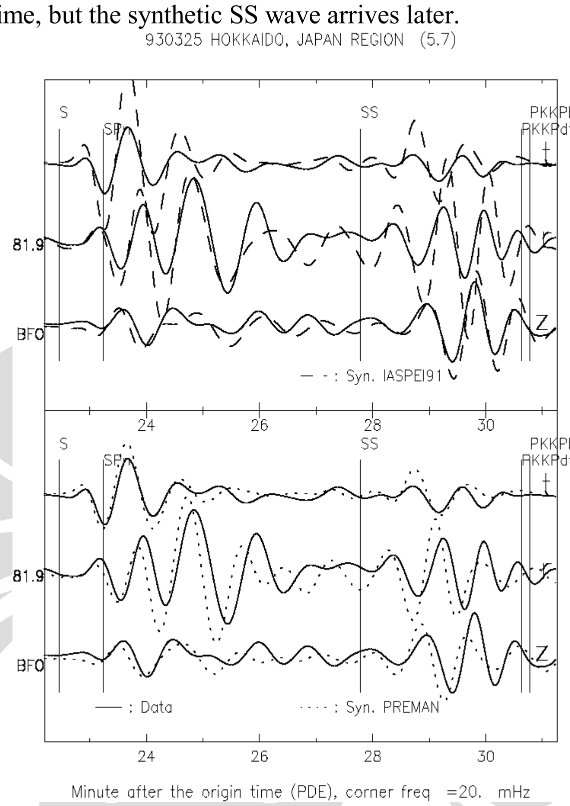


Figure 4. Seismogram comparison and travel time in time domain for time windows of S wave, 20 mHz

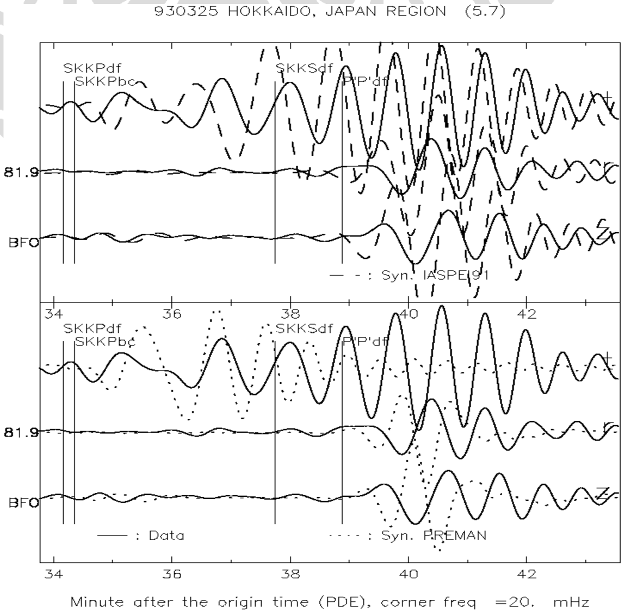


Figure 5. Seismogram comparison and travel time in time domain, time window of surface wave of Love and Rayleigh, 20 mHz

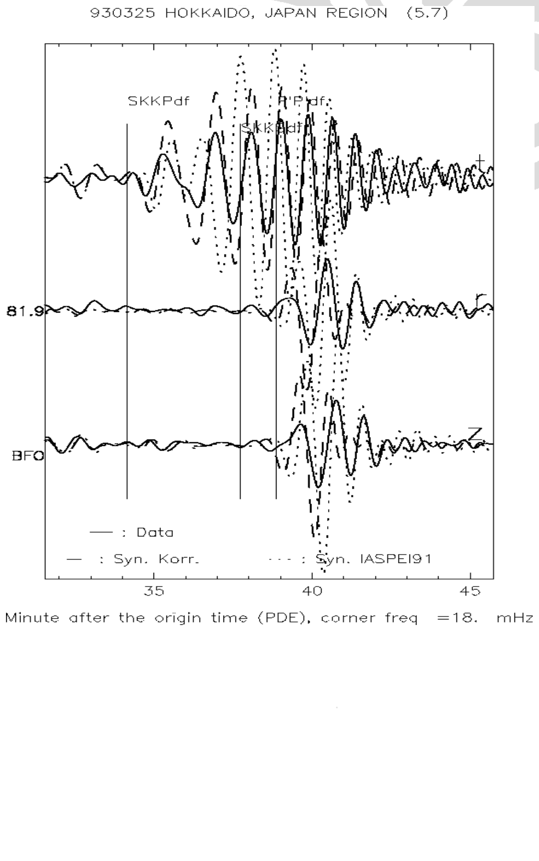
Seismogram comparison in time window of surface wave of Love and Rayleigh is given in Figure 5. It can be seen that earth model of PREMAN gives a shorter synthetic Love wave than the real Love wave, in trace with the t notation. If we pay attention more carefully on the arrival time of early phase of Love wave that the real and synthetic seismogram has discrepancy in waveform, whereas the seismogram comparison on surface wave of Rayleigh shows that the real and synthetic waveform have difference that almost 180^0.

In Figures 3, 4 and 5 we have seen the seismogram comparison in various time window, from P wave, S wave to surface wave of Love and Rayleigh. From three figures above we can see that discrepancies are so crowded. Both standard earth models give the seismogram synthetic that is far away from the real seismogram. It is interesting that the thickness of earth crust has influence on the amplitude height of body wave and oscillation amount in Love wave [12]. This phenomena is not yet been exploited in the determination of released energy by the earthquake [4].

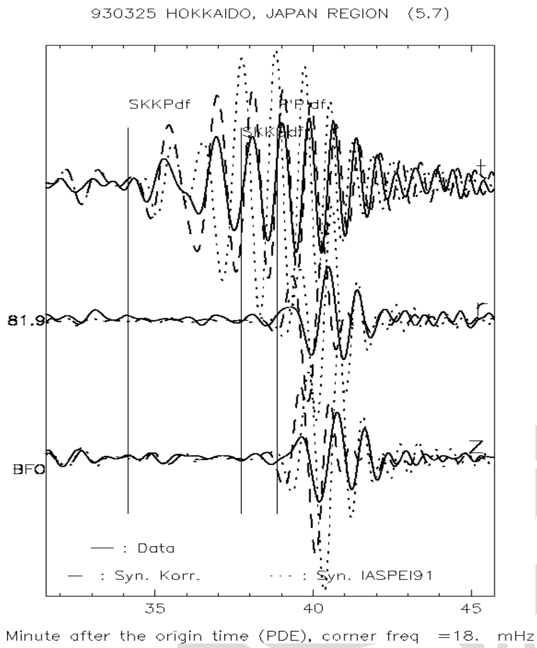
The hereinafter research is to accomplish the found discrepancies first at the waveform of Love and Rayleigh wave. This is conducted by altering the earth crust thickness and speed gradient of β_h and values of zero order coefficients of β_h and β_V in the upper mantle. Let us see its influence at seismogram comparison in time window of surface wave.

In Figure 6a we can see that arrival time from early phase, end phases, and oscillation amount in Love wave can better be simulated by the corrected seismogram. This fitting is obtained by changing the crust thickness, the speed structure by using a positive gradient of β_h and the values of zero order coefficient β_h and β_V in upper mantle. Whereas the correction at value of β_V gives a good fitting at Rayleigh wave. The surface wavelength is around 180 km, this is equivalent with the depth of surface wave propagation. The speed structure changing in these layers gives influence to the surface waves [13]. Figure 6b shows a seismogram comparison between corrected synthetic and synthetic from the IASPEI91 at time window of surface wave. It can be seen that early phase of Love wave by synthetic from IASPEI91 arrives later than the real, while the end oscillation of Love wave arrives earlier. Let we pay attention that height of second maximum of Rayleigh wave can better be simulated by corrected synthetic seismogram, but not at the first maximum. Good fitting is also obtained at end oscillations of Love wave.

The IASPEI91 earth model is formed only from travel time data, so that the yielded elastic parameters are only wave speed P and S wave. It is a surprise, that IASPEI91 earth model can give the better fitting on Love wave than from PREMAN model, is this only because of difference in earth crust thickness. Besides the IASPEI91 is in the form of isotropic earth model, although seismogram comparison at surface wave shows that there are differently discrepancies on both surface waves of Love and Rayleigh. The earth model should be an anisotropy earth model, that able to



(a)



(b)

Figure 6. Seismogram comparison and travel time in time window of surface wave of Love and Rayleigh, with corner frequency of 15 mHz. Corrected seismogram versus synthetic seismogram from (a) PREMAN (b) IASPEI91

accomplish the discrepancies on both surface waves simultaneously. Therefore henceforth seismogram comparison is relied on seismogram synthetic yielded from PREMAN and corrected earth model.

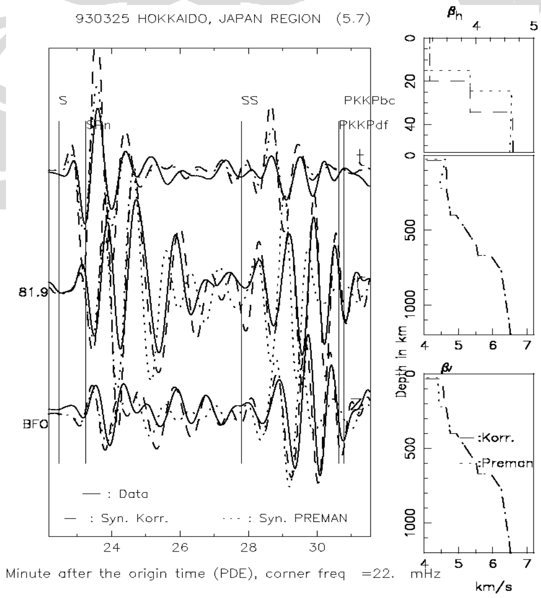


Figure 7. Seismogram comparison and travel time in time window of secondary waves S and SS with corner frequency of 20 mHz

Although speed change have been conducted only in upper mantle, Figure 7 shows influence into the repair in seismogram comparison in S and SS secondary wave. It can be seen that oscillation amount by S wave is better simulated, though the S synthetic arrives still 5.3 second earlier than the real S.

Figure 8 shows a good fitting between the synthetic and real seismogram at wave phase of body wave S and SS, at three components of ground movement simultaneously. The earth structure of S speed is altered down to a depth of 630 km to get the good fitting, although the speed change is very small, about 1 %. Good fitting is obtained at S wave on components of t and r, and SS wave on components of r and z. Wave phases with the small ripples which lay between end phase of S wave and early SS wave phase at component of r and z are excellently simulated by the corrected synthetic, but not by synthetic from PREMAN.

Figure 9 shows seismogram comparison between real and synthetic seismograms in wave phase of P and PP. It can be seen that the main maximum of P and PP waves can better be simulated by the corrected synthetic, as well as the end phase of the primary waves. It is true that the corrected synthetic has bigger amplitude than PREMAN synthetic, because for the fitting at Love wave needed a thicker earth crust thickness than PREMAN (Figure 6).

Effect from earth crust thickness to the amplitude height of body wave and especially Love wave is not yet been exploited for the determination of moment tensor, as explained in determination of CMT [4].

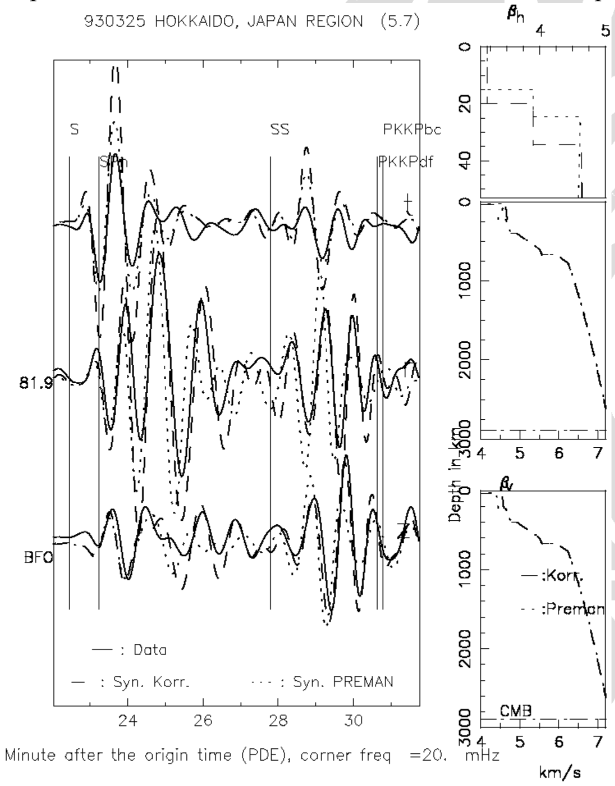


Figure 8. Seismogram comparison and travel time in time window of S and SS, with corner frequency mHz

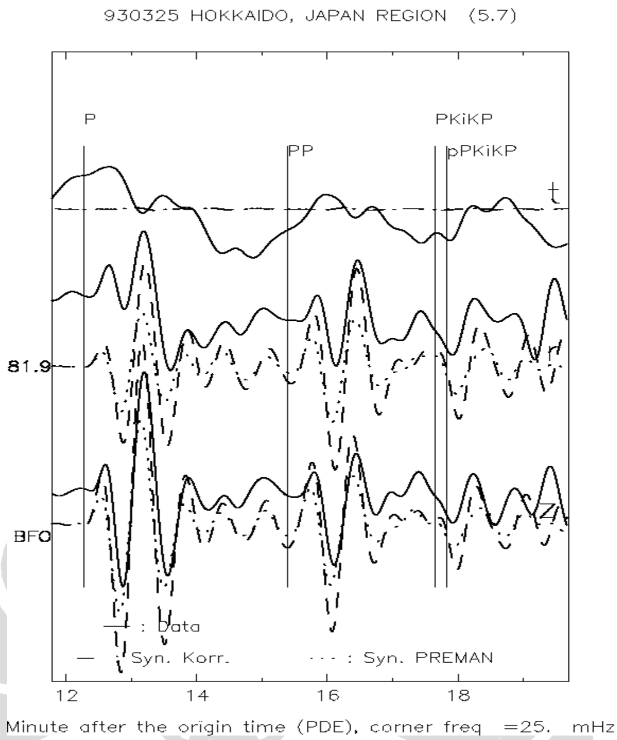


Figure 9. Seismogram comparison and travel time in time window of P and PP primary waves, with corner frequency of 25 mHz

4. Conclusion

Seismogram comparison between real and synthetic seismogram from standard earth model of PREMAN and IASPEI91 show the crowded discrepancies, if the comparison carried out in time domain and at three components of ground movement, although the corner frequency of the low-pass filter is set at 25 mHz. Difference of earth crust thickness among both standard earth models is clarified by amplitude of synthetic seismogram, that thicker earth crust gives the synthetic seismogram with the higher amplitude and longer oscillations at S, SS and Love waves, but the Rayleigh wave reacts little. Love wave with wavelength of 150 km reacts significantly to change covering the speed gradient of S, values of the coefficient order zero of speed structure in upper mantle and earth crust thickness. Fitting seismogram at surface wave of Love and Rayleigh also give the contribution at the repair on seismogram comparison at segment of S wave phase. Correction to wave speed in earth layers is furthermore continued down to a depth of 630 km, the change is under 1 %, so that a good fitting is obtained at time segment of S, SS, P and PP wave phases. The oscillation amount of Love wave is influenced by earth crust thickness, but also the amplitude height of body wave. This effect is not yet been exploited for the determination of moment tensor.

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