DETERMINATION OF CRUSTAL STRUCTURE BENEATH A BROADBAND STATION IN MALAYSIA USING RECEIVER FUNCTION ANALYSIS.

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ABSTRACT

We performed receiver function analyses in order to investigate crust structure beneath a broadband seismic station in Malaysia. We selected 11 teleseismic events from the Malaysian National Seismic Network Database whose magnitudes are in the range between 5.8 and 7.1 with good signal-to-noise ratios. We compared the observed receiver functions to the synthetic receiver functions computed for a model for the site of station IPM taken from the global crust model, CRUST 2.0. There is a significant difference between them. This is likely to be due to the thin sedimentary layer in the crust model, and our comparison suggests that such a sedimentary layer does not exist beneath the station site. Then, we applied a genetic algorithm to perform inversion. We modeled the crust and uppermost upper mantle with six major layers: sediment layer, basement layer, upper crust, middle crust, lower crust and uppermost mantle. The Moho depth is relatively well constrained and is estimated to be about 35km. The thin sedimentary layer is not obtained in the inversion result, although a thin layer with relatively low S wave velocity is obtained. This study is a preliminary attempt to determine velocity structures and obtain an appropriate velocity model for Malaysia. Further accumulation of data and stacking using a larger dataset will be useful to construct such a model by application of the data analysis procedure of this study.

Keywords: Receiver Functions, Crustal Structure, Genetic Algorithm.

1. INTRODUCTION

Malaysia is tectonically situated within relatively stable Sunda-land, and considered as a country with a very low seismicity. It is bordered to the west and to the east by the Indonesia (Indo-Australian Plate) and the Philippines (Philippines Sea Plate), which are two of the most seismically active countries in this region with frequent earthquakes. The Great Sumatra Earthquake with a magnitude of 9.3 on December 26th, 2004 caused a huge tsunami in the Indian Ocean that hit many countries including Malaysia. From that historical moment, Malaysian Government has decided to establish its own monitoring center. The main purpose of this study is to determine the crustal structure beneath a broadband station in Malaysia using a seismic data from the newly established seismic network.

2. DATA

To determine crustal structure, we chose a broadband station installed at Ipoh (its station code is IPM) in Malaysian Peninsula. We retrieved waveform data for 11 events from the Malaysian National Seismic Network Database whose magnitudes are in the range between 5.8 and 7.1 that occurred in the

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teleseismic distance range (Table 1). In order to obtain an effective receiver function modeling, we chose data with good S/N (signal to noise ratio).

Table 1. Teleseismic events used in this study.

Date	Mag (Mw)	Depth (km)	Azimuth (degree)	Epicentral distance (degree)	Slowness	Location
2/18/2010	6.9	573.8	30.15	46.50	0.071	China-Russia-North Korea
2/07/2010	6.3	16.5	46.91	28.98	0.081	Southwestern Ryukyu Island
2/26/2010	7.0	22.0	47.97	34.03	0.079	Ryukyu Islands, Japan
3/08/2010	6.1	446.5	66.99	44.42	0.072	Maug Islands Reg, N.Mar
1/27/2010	5.9	24.7	67.46	25.89	0.082	Philippine Islands Region
3/20/2010	6.6	423.5	97.88	51.72	0.068	New Ireland Region, P.N
2/01/2010	6.2	33.0	100.80	54.62	0.066	Bougainville Region, P.N
1/03/2010	6.6	10.0	103.40	55.02	0.064	Solomon Islands
1/05/2010	6.8	35.0	103.43	58.17	0.064	Solomon Islands
1/03/2010	7.1	30.5	103.50	56.99	0.064	Solomon Islands
4/11/2010	5.8	35.0	106.10	67.25	0.058	Santa Cruz Islands

3. THEORY AND METHODOLOGY

3.1. Receiver Functions

A waveform is a recorded time series of the earth movement beneath a seismic station (receiver). The relative response can be computed using three-component seismograms, vertical (Z), East-West (E-W), and North-South (N-S). Teleseismic waves arriving at a seismic station from different parts of the earth contains different information on the earth structure. Receiver function is one of the techniques to study the crustal structure. In receiver function analysis, information regarding earthquake source and the propagation through the mantle is removed from observed waveform data. We can extract information on structure of the earth's crust and uppermost upper mantle beneath a seismic station by analyzing the vertical and radial component records.

3.2. Data Preparation for Receiver Function Analysis

For receiver function analysis, we need three-component observations with a wide bandwidth period. We use SAC (Seismic Analysis Code) program to set several header variables (event latitude, longitude & depth and station latitude & longitude) in each waveform. The information is necessary for SAC program to rotate horizontal seismograms into the radial and tangential components by an angle of the back azimuth. The final data-preparation consists of windowing the P waveform from the pre-signal noise and the rest of the seismic signal. We are using signal of 60s before and after the arrival of the P wave. To avoid signal processing artifacts later in the processing, we remove the mean and taper the ends of signal. We used a program developed by Dr. Charles J. Ammon which is available at http://eqseis.geosc.psu.edu/~cammon/HTML/RftnDocs/prep01.html

3.3. Calculation of Receiver Function

The receiver function analysis uses the converted phases and multiples recorded on the horizontal seismograms (e.g., Langston 1977, 1979, 1981). It is necessary to isolate earth structure information from other factors. Teleseismic waves include conversions and reverberation phases generated at discontinuities beneath each station (Langston, 1979). Langston (1979) developed a source equalization procedure to remove the effects of near-source structure and source time functions. The impulse response of the earth structure for vertical components is assumed to be the Dirac delta function. We calculate receiver functions following Owens et al. (1984). To compute receiver functions, the vertical component signal is deconvolved from the radial component to produce source equalized radial seismogram (Ammon, 1991). For deconvolution, we used a water-level stabilization method and a low-pass Gaussian filter to remove high-frequency noise. A time series computed by this deconvolution is called a radial receiver function. The final expression for the radial receiver function in frequency domain is as follows

$$E_R(\omega) = \frac{D_R(\omega)\overline{D}_V(\omega)}{\varphi(\omega)} G(\omega)$$

Where $E_R(\omega)$ is Fourier transform of the radial receiver function, $D_R(\omega)$ is Fourier transform of the radial component of motion and $D_V(\omega)$ is Fourier transform of the vertical component of motion.

$$\varphi(\omega) = \max\left\{D_V(\omega)\overline{D}_V(\omega), c\max\left[D_V(\omega)\overline{D}_V(\omega)\right]\right\} \quad \text{and} \quad G(\omega) = e^{-\frac{\omega^2}{4\alpha^2}} \text{ (Gaussian Filter)}$$

c = water-level

3.4. Genetic Algorithm in Receiver Functions Inversion

Genetic algorithm is one of global search method (e.g., Sambridge and Drijkoningen, 1992). Genetic algorithm consists of reproduction step, crossover step, and mutation step. Genetic algorithms work with a group of Q (size of working population) models simultaneously, initially chosen at random, and code each into a binary string.

Table 2: Model parameters in genetic algorithm receiver function inversion.

		Sediment	Basement	Crust			Mantle
				upper	middle	lower	
Thickness (km)	Lower	0.0	0.0	5.0	5.0	0.0	0.0
	Upper	2.1	3.5	20.0	20.0	15.0	0.0
	n	3	3	4	4	4	0
	Increment	0.3	0.5	1.0	1.0	1.0	0.0
Vs(km/s)	Lower	1.5	2.2	2.9	3.1	3.3	4
	Upper	2.2	2.9	3.6	4.0	4.0	4.7
	n	3	3	3	3	3	3
	Increment	0.1	0.1	0.1	0.1	0.1	0.1
Density(g/cc)	Lower	1.70	2.30	2.67	2.18	3.18	3.25
	Upper	2.40	2.60	2.67	2.18	3.18	3.25
	n	3	2	0	0	0	0
	Increment	0.1	0.1	0.0	0.0	0.0	0.0
Vp/Vs	Lower	1.80	1.80	1.73	1.73	1.73	1.73
	Upper	2.50	2.10	1.73	1.73	1.73	1.73
	n	3.0	2.0	0.0	0.0	0.0	0
	Increment	0.1	0.1	0.0	0.0	0.0	0.0
Qα		100	675	1450	1450	1450	1450
Qβ		25	300	600	600	600	600

We have modeled the crust and uppermost mantle with six major layers: sediment layer, basement layer, upper crust, middle crust, lower crust and uppermost mantle. The model parameters in each layer are thickness, S wave velocity, density, and the velocity ratio between Vp/Vs. These model parameters are represented by a binary string. The length of the binary string is 46. For each model parameter, upper limit, lower limit and 2^n possible values are specified. The best model is searched within these limits. The total number of model parameters is 15. The ranges of the model parameters, the n values and the incremental values are shown in Table 2. The total size of model space to be searched is 2^{46}. The inversion procedure was iterated for 200 generations; as a result 200,000 models were generated. The radial receiver functions for IPM station were inverted using this technique. We used the code developed by Shibutani et al. (1996) to perform inversion of receiver functions for crustal structure.

4. RESULTS AND DISCUSSION

4.1. Observed and Synthetic Receiver Function

Velocity structure in crust and uppermost upper mantle beneath seismic stations can be determined by inversion of receiver functions with time duration about 30-40 second (Owen et al., 1984). Before performing receiver function inversion, we compared the observed receiver functions to synthetic receiver functions computed for an existing crust model for the station site. In this analysis, we used CRUST 2.0 (http://igppweb.ucsd.edu/~gabi/crust2.html) to compute synthetic receiver functions. Figure 2 shows P and S wave velocity structure for IPM station. There is a thin sedimentary layer exist with S wave velocity of 1.2km/s in this model. The Moho thickness beneath the IPM station is about 32.5km.

Figure 3 shows a comparison of the observed and synthetic receiver functions. There are significant differences between them. In the synthetic receiver function there are several peaks in the early part (say, 0-2 s), while there is one peak in the observed receiver function. These peaks in the synthetic receiver function may be caused by the thin sedimentary layer in the model taken from CRUST2.0. To investigate this possibility, we replace the sedimentary layer by the layer with the underlying upper crust property to make another synthetic crust model. Then we recalculated the synthetic receiver function for this modified model. The computed receiver function is shown in Figure 3(c). The several peaks found in the receiver function shown in Figure 3(b) disappear. This result suggests that these peaks are produced by the thin sedimentary layer. Since the receiver function computed for the modified model (i.e., there is no thin sedimentary layer) is more similar to the observed receiver function, the thin sedimentary layer is not likely to exist beneath station IPM.

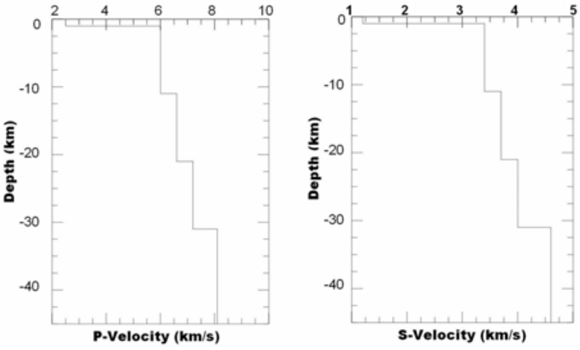

Figure 2. P and S wave velocity models for IPM station taken from CRUST 2.0 model are shown in the left and right panels, respectively.

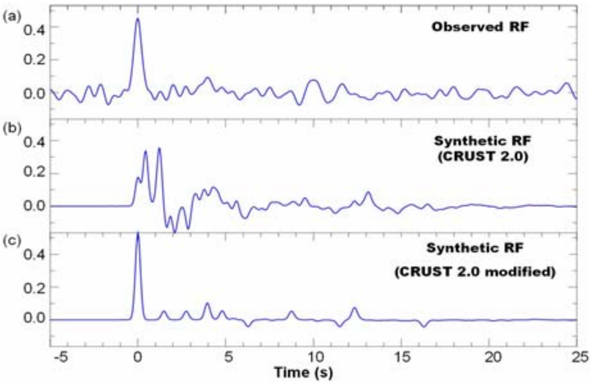

Figure 3. Radial receiver functions (a) observed, (b) synthetic computed for the model shown in Figure 2, and (c) the modified model, for the 18/2/2010 event that occurred in China-Russia-North Korea.

4.2 Receiver Functions Inversion by Genetic Algorithm

Among the 11 receiver functions that we calculated, we chose those for the events that occurred on 2/07/2010 and 2/26/2010 to perform inversion based on signal-to-noise ratios, their similarity, back azimuths and epicentral distances. Then, following the suggestions by Dr. Ammon the receiver functions are down-sampled from 20 Hz to 10 Hz, and the signals up to 20 second from the P onset are used for inversion. Figure 4 shows the best model for which the residual between the observed receiver function and the synthetic receiver function is the smallest. There is no sedimentary layer in this model, while there is a thin layer with a relatively low velocity. Figure 5 shows comparison between the observed receiver function and the synthetic receiver function computed for the model shown in Figure 4. Some significant features are reproduced, although there are several differences. Figure 6 shows the models for which the residuals between the observed receiver functions and synthetic receiver functions are comparable (up to 2 per cent difference) to that for the best model shown in Figure 4. The Moho depth seems relatively well constrained to be around 35 km, while the density and the Vp/Vs ratios of the shallow layers are not well constrained.

To quantitatively evaluate the uncertainty of the inversion result, we calculated marginal posteriori probability density functions for each model parameter using all of the models generated in the inversion. Figure 7 shows the probability of thickness for each layer. The values and shapes of probabilities indicate whether the parameter in each layer is well constrained or not. We can see the thickness in each layer is well constrained with a value of Moho depth about 35km. This is consistent with the results show in Figure 6.

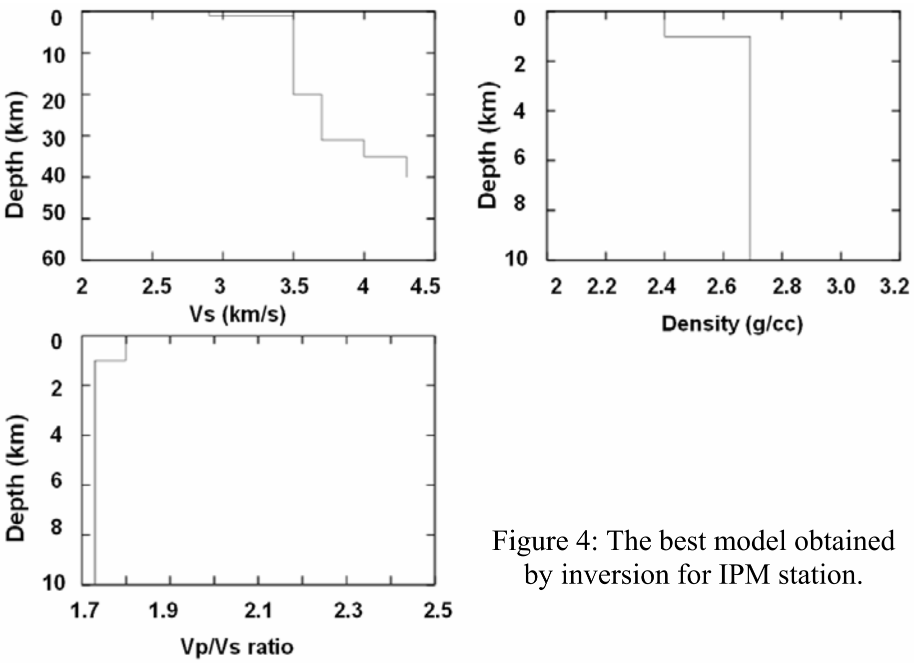

Figure 4: The best model obtained by inversion for IPM station.

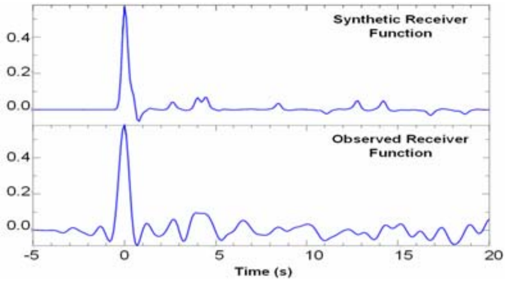

Figure 5. Comparison between the synthetic receiver function and the observed receiver function.

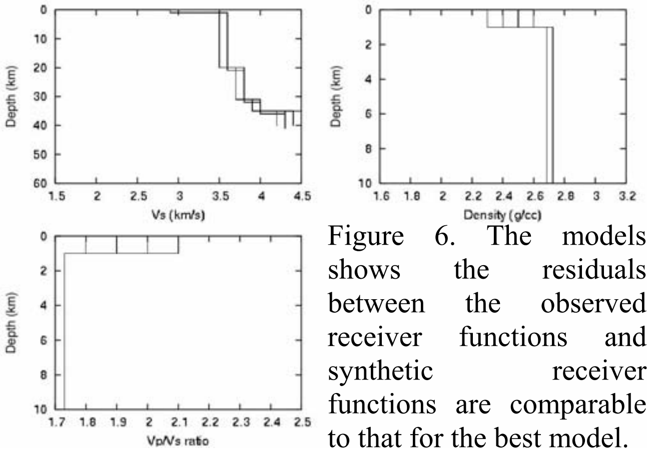

Figure 6. The models shows the residuals between the observed receiver functions and synthetic receiver functions are comparable to that for the best model.

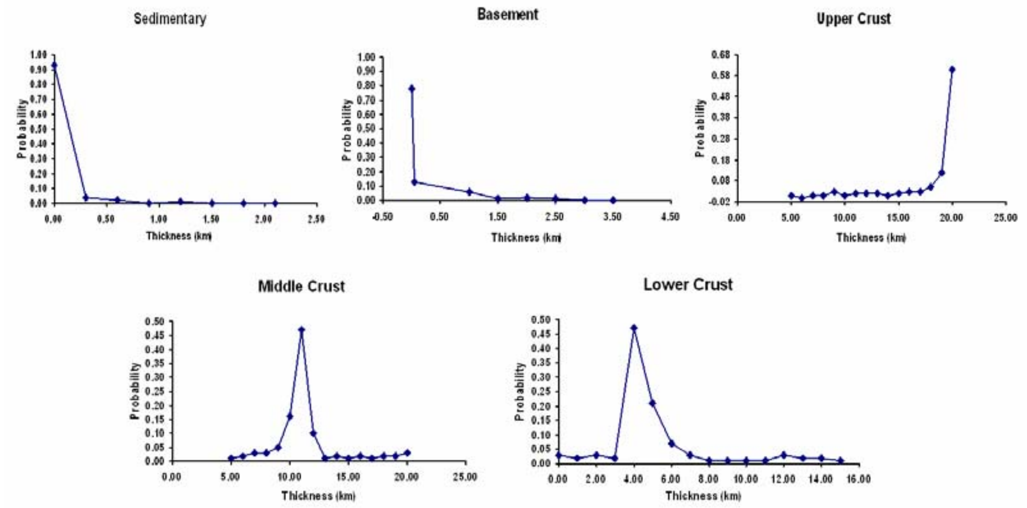

Figure 7. Marginal posteriori probability density functions for thickness in each layer.

5. CONCLUSIONS

In this study, we performed receiver function analysis to determine the crustal structure beneath the broadband station IPM in Malaysia. We used data from the 11 teleseismic events with magnitudes in the range between 5.8 and 7.1 from the Malaysian National Seismic Network Database. We calculated receiver functions by deconvolving vertical components from radial components with water levels to make computations stable. Before performing inversion for structure, we computed synthetic receiver functions for IPM station. The crust model is chosen from the global crust model, CRUST 2.0; the model contains a thin sedimentary layer with S-wave velocity of 1.2km/s. There is a significant difference when we compared synthetic receiver functions to the observed receiver functions. The differences suggest that such a sedimentary layer does not exist beneath the station.

Then, we applied a genetic algorithm to perform inversion of the observed receiver functions for crustal structure beneath IPM station. We chose the receiver functions from two events for inversion based on signal-to-noise ratios, their similarity, back azimuths and epicentral distances. There is no sedimentary layer in the obtained model, while there is a thin layer with a relatively low velocity. Some significant features of the receiver functions are reproduced by the obtained model. We calculated marginal posteriori probability density functions for each model parameter using all of the models generated in the inversion. The thickness for each layer, the S-wave velocities in the crust and the Moho depth is relatively well constrained, which suggests that the Moho depth beneath IPM station is around 35km. Constraints for Vp/Vs ratios and densities in the sedimentary and basement layer seem weak.

This is the first receiver function analysis done using data from the Malaysian National Seismic Network. When we compare our results to the model from CRUST2.0 a significant difference is found for the very shallow structure beneath the IPM station. Our results suggest that there is a thin layer with a relatively low S-wave velocity and that the sedimentary layer in the CRUST2.0 model does not exist. Further accumulation of data and application of the technique used in this study will be useful for construction of a crust model appropriate for Malaysia.

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