RAYLEIGH WAVE PHASE VELOCITIES OBTAINED USING DATA FROM THE MALAYSIAN NATIONAL SEISMIC NETWORK

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ABSTRACT

This study is an attempt to measure phase velocities using broadband waveform data from the Malaysian National Seismic Network (MNSN). We applied two-station method in the measurements of phase velocities of the fundamental mode Rayleigh waves. We selected 10 distant large (M>=6.5) earthquakes that occurred in 2009 and 2010. We computed the phase velocities using a cross-correlation technique for fundamental mode Rayleigh waves which were edited based on a range of group velocities between 2.6 and 4.0 km/s with visual checks of the waveforms. We computed two theoretical phase velocities based on PREM (with and without ocean) in calculation of phase velocities. The phase velocity measurements are divided into three groups based on the difference of paths (i.e., the Malay Peninsula, the Borneo Island, and the South China Sea (ocean path)). We computed average phase velocities for these groups. For the Borneo Island, the standard deviation is relatively larger due to larger scattering of the measurements. For this reason, we only discuss the results for the ocean path and the Malay Peninsula. The average phase velocities obtained for the Malay Peninsula and the ocean path are not largely different from theoretical phase velocities calculated for PREM. In order to investigate effects of crust structures for the phase velocities, we constructed seven structure models referring to CRUST2.0, and computed phase velocities for them and model iasp91. These phase velocities relatively well explain the observed phase velocities at shorter period range (30-90 s). The differences between the observed and theoretically computed phase velocities at longer period range (100-140 s) may indicate the differences of mantle structures beneath these regions.

Keywords: Crust structure, Two-station method, Rayleigh wave, CRUST2.0

1. INTRODUCTION

The Malay Peninsula is a part of West Malaysia whilst Sabah and Sarawak are parts of East Malaysia. Based on the tectonic setting, Malaysia underlies the stable Sundaland of the Eurasian plate and the seismicity in Malaysia is considered to be very low. It is bordered by two of the most seismically active plate boundaries between the Indo-Australian and the Malay Peninsula and between the Sabah and Sarawak and the Philippines Sea Plate. After the Sumatra earthquake occurred on 26th December 2004, the Malaysia government has established the monitoring center in order to strengthen the monitoring network . This study is an attempt to measure phase velocities using waveform data from the Malaysian National Seismic Network (MNSN) and to have inferences on crustal structures in and around Malaysia by comparison between observed phase velocities and those theoretically calculated for various models.

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2. METHODOLOGY

We apply two-station method (e.g., Dziewonski and Hales 1972) in this study, in order to avoid the difficulties with the source phase shift. By assuming both stations are at the same azimuth from an epicenter, the equations for both stations are given as follows:

$$k(w).r_1 = \phi_1(r_1, \theta, \omega) - \phi_0(\theta, \omega) - \phi_{i1}(\omega) + 2n\pi \,, \tag{1}$$

$$k(w).r_2 = \phi_2(r_2, \theta, \omega) - \phi_0(\theta, \omega) - \phi_{i2}(\omega) + 2m\pi \,, \tag{2}$$

where, r_1 and r_2 are distance between epicenter and station 1 and station 2, respectively, ϕ_{i1} and ϕ_{i2} are instrumental phase shift of station 1 and station 2, respectively, ϕ_0 source phase shift, m and n are integer number of the phase cycles. By simplifying the Eq.(1) and (2), we can obtain the following relations between the phase velocity and the phase differences.

$$C(\omega) = \frac{\omega}{k(\omega)} = \frac{\omega(r_2 - r_1)}{\phi_2 - \phi_1 - \phi_{i2} + \phi_{i1} + 2l\pi} . \tag{3}$$

3. DATA ANALYSIS AND THEORETICAL PHASE VELOCITY COMPUTATION

The basic procedure of the analysis for this study was shown below (Figure 1).

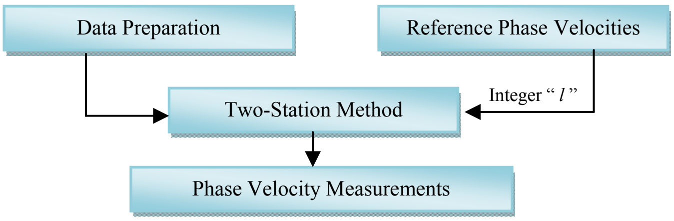


Figure 1. Procedure of phase velocity measurement.

3.1. Data Preparation for Phase Velocities Measurements

We need vertical component of long period seismograms. We retrieved data from Incorporated Research Institution for Seismology (IRIS), Data Management Center (DMC) available at http://www.iris.edu/wilber. We 10 events in that occurred in 2009 and 2010 (Table 1) from the Malaysian National Seismic Network Database with magnitudes ranging between 6.5 and 8.0. We considered the fundamental mode of Rayleigh wave and we set the start and end times of data to 2 minutes before P arrival and 100 minutes after P arrival, respectively. All the data are in the Standard for Exchange of Earthquake Data (SEED) format and we need to convert the data to Seismic Analysis Code (SAC) using rdseed version 5.0 program in order to start the data analysis.

	LAT	LONG	DEPTH	MAG	DATE	TIME (UTC)	LOCATION
1	-23.08	-174.2	49.1	7.6	2009 03 19	18:17:53	TONGA ISLANDS
2	16.5	-87.17	12	7.3	2009 05 28	8:25:05	NORTH OF HONDURAS
3	-45.85	166.26	23.5	7.8	2009 07 15	9:22:50	OFF W. COAST OF S. ISLAND N.Z.
4	29.039	-112.9	18	6.8	2009 08 03	17:59:56	GULF OF CALIFORNIA
5	-11.61	166.09	47	6.6	2009 08 10	4:06:31	SANTA CRUZ ISLANDS
6	-15.22	-172.6	7	6.5	2009 08 30	14:51:33	SAMOA ISLANDS REGION
7	-15.13	-172	12	8.1	2009 09 29	17:48:27	SAMOA ISLANDS REGION
8	-13.14	166.09	13.8	6.7	2009 10 08	8:28:53	VANUATU ISLANDS
9	-20.85	-173.6	25.9	6.8	2009 11 24	12:47:22	TONGA ISLANDS
10	-43.53	171.81	12	7.0	2010 09 03	16:35:47	SOUTH ISLAND,NEW ZEALAND

Table1. List of the events used in this study.

3.2. Time window of Fundamental-mode of Rayleigh Wave

Before the suitable Rayleigh wave train was obtained for further analysis, we listed all the possibilities of station pairs that situated near or on the same great circle path. In this case, we set the threshold value for the azimuthal difference between the two stations to 1.0 degree. (e.g., Yoshida and Suetsugu 2004). Therefore, the epicenter and the two stations are near or on approximately the same great circle path. In this study, a time-window for fundamental mode Rayleigh wave was computed based on a range of group velocities between 2.6 km/s and 4.0 km/s. After visual checks, we changed this range if necessary.

3.3. The Computation of Theoretical Phase Velocity

We computed theoretical phase velocities for reference models in order to select an appropriate value for an integer $\boldsymbol{l}$ in Eq.(3). An integer $\boldsymbol{l}$ is chosen so that the phase velocities are consistent with those computed for the reference model. As for the reference models, we used Preliminary Reference Earth Model (PREM) (Dziewonski and Anderson 1981) with and without ocean for the ocean and the land paths, respectively. As for the calculations, we used MINEOS package from CIG (Computational Infrastructure for Geodynamics, http://www.geodynamics.org/cig/software/mineos).

4. RESULTS AND DISCUSSION

For the calculation of phase velocities, we used the formula in Eq.4 (e.g., Yoshida and Suetsugu 2004). We computed the phase velocities using a cross-correlation technique for fundamental mode Rayleigh waves which were edited based on a range of group velocities between 2.6 km/s and 4.0 km/s and performed the visual checks of the waveforms.

$$C(f) = \frac{2\pi f x}{2\pi f t_0 + \phi(f) \pm 2n\pi} \quad , \tag{4}$$

where, $C(f)$ is phase velocity at a frequency f, x is distance between two stations, $\phi(f)$ phase difference at a frequency, t_0 is reference time difference between the two stations and n is integer number of the phase cycles.

4.1. Analysis of the Ocean Path

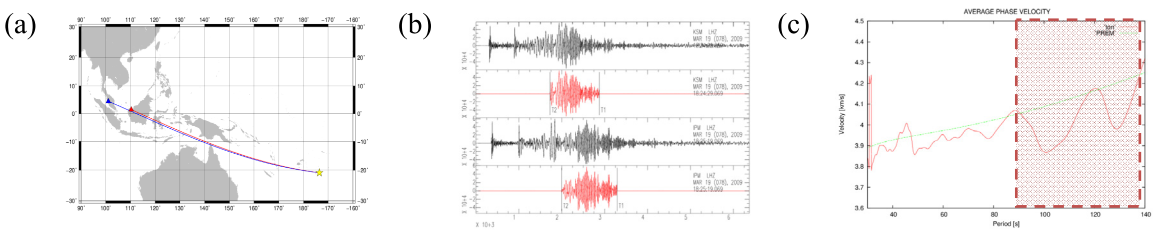
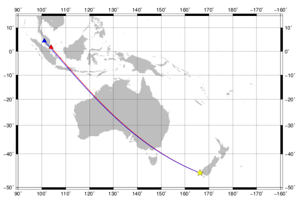


Figure 2. (a) The locations of the epicenter (star) and stations KSM (red triangle) and IPM (blue triangle) and the ray paths. The event is occurred at Tonga Islands, on 19 March 2009, Origin time:18:17:53, Magnitude:7.6, Depth: 49.1km. (b) The observed raw vertical component recorded at KSM and IPM stations and the edited waveforms are shown respectively.(c) The obtained phase velocity.

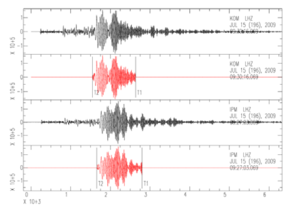
Figure 2(a) shows the locations of the epicenter and the stations and the ray paths. Figure 2(b) shows the observed raw vertical component and the edited waveforms recorded at KSM and IPM stations, respectively. The edited waveforms (shown in red) are obtained from the group velocity in the range 2.6 and 4.0km/s. Figure 2(c) shows that the dispersion curve is slower than the reference model PREM in the range period 30–90s. The dispersion curve in the period range longer than 100 s (pink shaded) was discarded considering a large fluctuation in this case.

4.2. Analysis of the Malay Peninsula (land path)

(a)



(b)



(c)

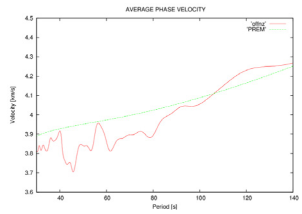
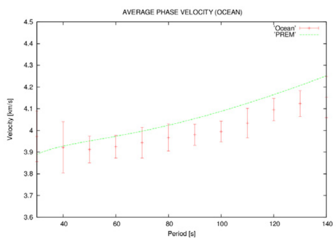


Figure 3. (a) The locations of the epicenter (star) and stations KOM (red triangle) and IPM (blue triangle) and the ray paths. The event is occurred at Off the W.Coast of S.Island, NZ , on 15 July 2009, Origin time: 09:22:50, Magnitude:7.8, Depth: 23.5km. (b) The observed raw vertical component recorded at KOM and IPM stations and the edited waveforms are shown respectively.(c) The obtained phase velocity.

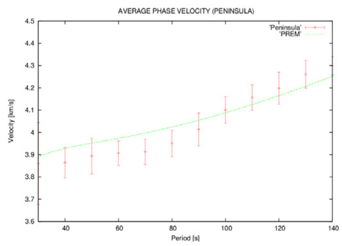
Figure 3(a) shows the locations of the epicenter and the stations and the ray paths. Figure 3(b) shows the observed raw vertical component and the edited waveforms recorded at KOM and IPM stations, respectively. Figure 3(c) shows the dispersion curve is slower than the reference model PREM in the range period 30s – 110s and faster in the range period 115s – 140s.

4.3. Average of Phase Velocities Measurement

(a)



(b)



(c)

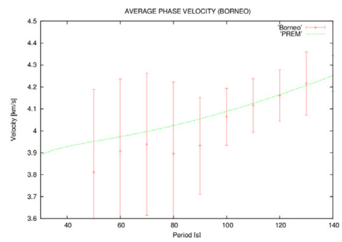


Figure 4. The average phase velocities obtained in this study compared with the model PREM (green broken curve). (a) The average of the phase velocities for ocean path mainly the station pair crossing the South China Sea. (b) The average of the phase velocities for the Malay Peninsula (land path). (c) The average of the phase velocities for Borneo Island (land path).

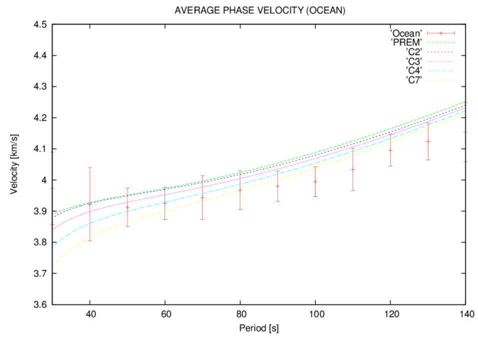
Figure 4 shows the average phase velocity and their standard deviations computed at respective periods. Based on Figure 4(c), the standard deviation is much larger for the Borneo Island path compared with the ocean path (Figure 4(a)) and the Malay Peninsula (Figure 4(b)). This is due to larger scattering of the measurements. For this reason, we only discussed the results for the ocean path and the Malay Peninsula. The average phase velocities obtained for the Malay Peninsula and the ocean path in the period range 30-90 s are not largely different from those computed for PREM considering their standard deviations. In the longer period range (100s-140 s) they show some differences and it may indicate the differences of mantle structures beneath these regions.

4.4. The Computation of the Reference Model from CRUST2.0

In order to investigate the effects of crust structures for the phase velocities, we computed phase velocities for seven models which we constructed referring to the CRUST2.0 (Bassin et al. 2000; http://igppweb.ucsd.edu/~gabi/crust2.html). In addition, we showed the theoretical phase velocity for model iasp91 in Figure 6(b).

In Figure 5(a), model C7 provided the best fit for the ocean path in the period range between 30-140 s. Considering the standard deviations, the observed phase velocity is consistent with the phase velocity for this model, although in the shorter period (30-80 s) the observed phase velocity is faster than that of model C7 whilst in the longer period (90-130 s) the observed phase velocity is slower than that of model C7. Figure 5(b) showed that model J3, J4 and iasp91 provided the best fit for the Malay Peninsula path. For the land path, in the shorter period (30-90 s) the observed phase velocity is slower than those for these models whilst in the longer period (100-130 s) the observed phase velocities is faster than those for these models. The effects of the crust structures for phase velocities are significant for the shorter periods and they become smaller in the longer period range. We can consider the phase velocities computed for models constructed from CRUST2.0 relatively well explained the observed phase velocities at shorter period range. The differences between the observed and the theoretically computed phase velocities at longer period range may indicate the differences of mantle structures beneath these regions.

(a)



(b)

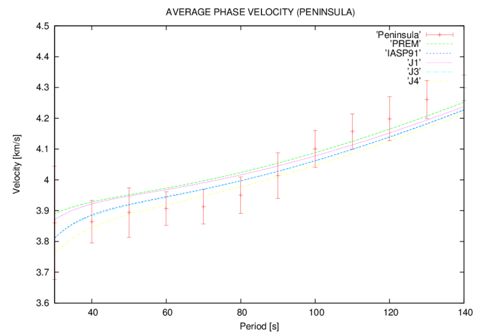


Figure 5. A various theoretical models constructed from CRUST2.0. (a) The ocean path and (b) The Malay Peninsula, respectively.

4.5. The Comparison with other studies

Lebedev and van der Hilst (2008) applied the Automated Multimode Inversion (AMI) of surface and S-wave forms to obtain a S_v-velocity model of the upper mantle (crust-660km). The S_v-velocities beneath the ocean paths of this study is slower in their model at depths range 80-150 km. As we discussed above, the phase velocity for the ocean path is a little slower in the period range 90-130s, therefore, the result that we obtained in this study for the ocean paths is qualitatively consistent with their model.

Din (2010) performed the receiver function analysis and suggested that the crust thickness beneath the IPM station is around 35 km which is similar to the model iasp91. Mat Said (2011) showed the travel time data for the Malaysian National Seismic Network can be well explained by model iasp91. The results of this study are consistent with their result of studies.

5. CONCLUSIONS

In this study we measured phase velocities using waveform data from the Malaysian National Seismic Network. We used 10 selected events that occurred in 2009 and 2010 with magnitudes in the range between 6.5 -8.1. We retrieved the vertical component long period waveform data from IRIS, DMC. We computed the phase velocities using a cross-correlation technique for fundamental mode Rayleigh waves which were edited based on a range of group velocities between 2.6 and 4.0 km/s with the visual checks of the waveforms. We computed two theoretical phase velocities models based on PREM (with and without ocean) to apply the two station method.

We divided the phase velocity measurements into three groups based on the difference of paths (i.e. the Malay Peninsula, the Borneo Island and the South China Sea (ocean path)). The average phase velocities obtained for the Malay Peninsula and the ocean path in the period range 30-90 s are not largely different from theoretical phase velocities calculated for PREM. For the Borneo Island, the standard deviation is much larger due to larger scattering of the measurements.

We compared the average phase velocities obtained in this study with the phase velocities computed for various theoretical models constructed from CRUST2.0 and for iasp91. The phase velocities computed for these models relatively well explain the observed phase velocities at shorter period range (30-90 s). For the ocean path, model C7 provided the best fit whilst for the Malay Peninsula, models J3, J4, and iasp91 provided the best fit.

The effects of the crust structures for phase velocities are significant for the shorter periods and they become smaller in the longer period range. The observed phase velocities for the Malay Peninsula are faster in the longer period range (100-130 s) whilst for the ocean path the phase velocities are slightly slower in the longer period range (100-130 s).This differences may indicate the differences of mantle structures beneath these regions.

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