Ambient Noise Tomography for Determining the Velocity Model of Rayleigh Wave in Java Island, Indonesia

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Abstract

Ambient Noise Tomography had been applied to describe the Rayleigh wave group velocity model in the crust of Java Island, Indonesia. The collected seismic data consist of vertical component that recorded in January to December 2011 from 12 seismic stations at Indonesia Tsunami Early Warning System (INA TEWS) BMKG network Seismograph in Java Island. The waveform data processing was conducted from the preparation stage of daily waveform data, signal conditioning to signal cross correlation between paired stations that produced the empirical green function of the medium where the signal propagated. The estimated travel time of Rayleigh wave group for both periods of 5 s and 20 s were obtained from the time delay of the cross correlation. There were obtained by 36 and 22 traces respectively. The tomography process was conducted by using FMST v1.1 where forward and inverse modeling performed iteratively. The modeling result for the period of 5 s shown that the distribution of negative anomalies corresponded to volcanoes and Inter-Volcano plains which were Quarter-old. For period of 20 s, the western part of Java Island had a lower velocity anomaly than the eastern Java. This indicated that the tectonic activity of the western Java was more complex.

Keywords

tomography, ambient noise, cross-correlation, Rayleigh

I. INTRODUCTION

Java Island lied on the subduction zone of two major plates. The Indo-Australian Plate moving relative to the north under the Eurasian plate that moves relative to the south. This condition led to Java Island has a fairly complex geological and tectonic order characterized by a mountainous pathway that stretches from west to East on Java Island. The frequent series of tectonic and volcanic disasters caused of them. Furthermore, the study of the subsurface structure of Java Island became interesting to learn, especially in the field of geophysics.

Seismic tomography is a method to describe the subsurface condition using seismic data recorded on the earth surface. Most seismic tomographyis performed using waveform data from earthquakes occurring in a region and recorded on some seismograph equipment networks. For areas with high seismicity, this method is good enough to provide information about the subsurface structure of the earth. For areas that are aseismic this method is difficult to implement because in its implementation is very dependent on the earthquake as a source and seismograph network that record it. Although Java Island has a high seismicity level, the relatively dominant centre of earthquake located in the south can result in uneven resolution of tomographic images generated by earthquake tomography.

A new method of tomography was developed by Campillo[1] by using ambient noise signals as the main ingredient. This research has been conducted in various parts of the world such as California, USA[2], South Korea [3], Tibet[4], Europe[5], New Zeeland[6], Australia [7]and several other areas. Ambient noise is an elastic wave that travels through the earth and it is not generated by earthquakes or explosions [8]Ambient noise is often overlooked because it is not impulsive. These signals are usually discarded or not taken into account in seismic data analysis. However, a new method is able to prove that ambient noise signals can be useful to provide information about subsurface conditions. By using ambient noise tomography, the resolution of tomographic images is no longer dependent on earthquake occurrence but depends only on the distribution of existing seismograph networks.

Rayleigh wave tomography that utilizes earthquake waveforms is only able to describe perturbation with periods over 20 seconds while the period below 20 seconds will be attenuated before it could be recorded by a seismograph. The ambient noise tomography is able to describe the velocity of Rayleigh waves with periods under 20s, so that it could illustrate the shallow structures of the Earth's crust and the upper mantle.

The tomographic study on Java Island conducted by Widyantoro et al interpreted earth structures with depths of more than 350 km using P and S waves [9]. In this study we described the 2-D Rayleigh wave velocity model in the upper crust of Java Island using the travel time estimation from result of ambient noise signal cross correlation.

The research materials in this study were the waveform data of vertical component of broadband seismometer from 12 Indonesian network station Tsunami Early Warning System (Ina TEWS) BMKG spread in Java Island from January to December 2011.

II. METHODS

A. *Tomography*

Tomography is a special technique that can be used to get the contents of an object with a solid object without cutting or slicing it. It is performed by taking measurements outside the object from various directions to make projections, then reconstruct [10]. Step by step of research could be explained as in Fig. 1.

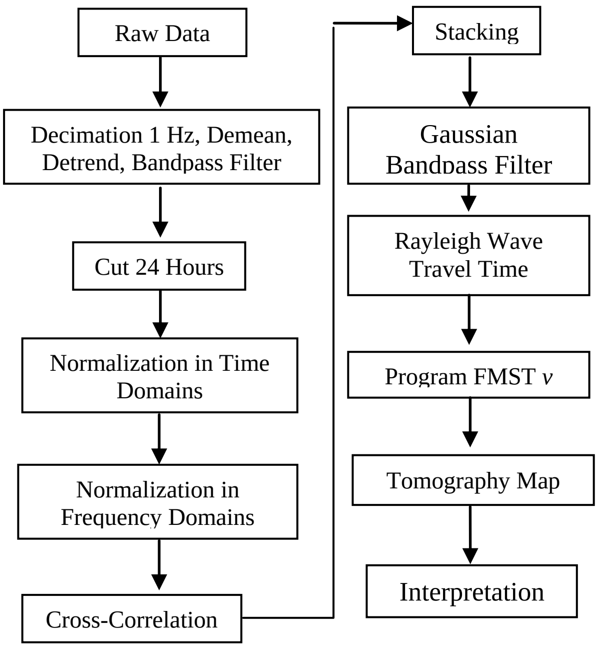


Fig. 1: Research Flowchart

B. *Ambient Noise*

Ambient noise commonly known as natural vibrations is an elastic wave that travels through the earth and is not generated by earthquakes or explosions [11]. Noise comes from two main sources of nature and man. At low frequencies below 1 Hz, the ambient noise source is nature. While the frequency above 1 Hz the main source is human activity such as vehicle traffic.

The series of studies on ambient noise has been getting a lot of attention lately. The most important thing is the seismic noise cross correlation of two stations capable of studying the wave propagation model between the two stations. Tomography using surface waves measured using empirical green function has become a valuable tool for determining the structure of the crust with high resolution.

C. *Sequence Expansion Method*

The sequence expansion [12]assumes the object studied becomes a collection of discrete cells. The emitted rays of the source propagate through a portion of the cell. The rays propagate toward the receiver and provide projection of the parameters present in each cell. Based on the data received can be determined the structure of the object.

The series expansion method performs an iterative improvement of the model function from calculation result (M^{est}) convergent approximating the actual model function (M^{true}). This repair process is performed by comparing the observed data function (P^{obs}) with the forecasting data function (P^{pre}) used forward modeling. For a series of sources and receivers, the function of the *M(r)* model of wave propagation can be written as in Eq.1:

$$P^{obs} = \int_{ray} M^{true}(r)\,dr \qquad (1)$$

The propagation of a single wavelet through the discrete model function can be written with the equation in discrete form (Eq. 2).

$$P_i = \sum_{j=1}^{J} M_j S_j \qquad (2)$$

Where *Mj* is a calculated model function for *j*-cell, *Sj* is the wavelength through the *J*-cell and *J* is the total cell in the model function.

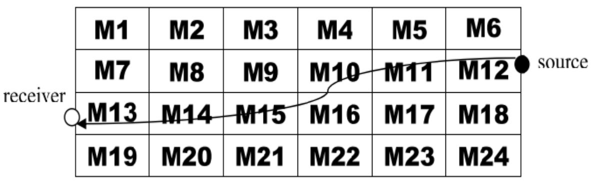


Fig. 2: An example of wave propagation in a cell model

The distribution of a wave ray as shown in Fig.2 is through 7 cells. Cells in the model that are not passed by the wave ray will have a value of Sj = 0. To get information about the cells that have not been known then it is propagated other wave rays by adding more recipient source pair. The equation involving all the rays of the wave through the function of the model is as Eq. 3:

$$P_i = \sum_{j=1}^{J} M_j S_{ij} \text{ , } i=1, \ldots I \qquad (3)$$

Where I is the total wave ray, Sij is the length of the i rays through the j-cell, Mj is the discrete model function for j cell, and J is the total number of cells.

Eq. 3 is a formulation for forward modelling used in the expansion of the seismic ray tomography series. Eq. 3 can be used to model effectively if Pi, i = 1, ..., I, is real data (travel time) and model function Mj, j = 1, ..., J, is a function of the actual model but it is not known yet. it can also be written as Eq. 4:

$$P_i^{obs} = \sum_{j=1}^{J} M_j^{true} S_{ij} \text{ , } i = 1, \ldots I \qquad (4)$$

The equation above (Eq. 4) can be written in matrix form as follows:

$$d = Gm \qquad (5)$$

where :

d : Vector data

m : Vector model

G : The linear operator to predict data from the model

Eq. 5 relates the slowness of the object investigated with the travel time of the measured object. If we measure the travel time and know the geometry of the rays, then the slowness of Eq. 5 above can be calculated as follows (Eq.6).

$$m = G^{-1} d = \left(G^T G^{-1}\right) G^{-1} G^T d \qquad (6)$$

However, Eq. 6 in practice is difficult to solve because the matrix is too large and rarely then it will be zero and G is singular. The problem could be solved by using inverse method of Singular Value Decomposition (SVD) matrix.

III.RESULT AND DISCUSSION

After preparation process for all daily waveform data, the next step was to perform cross correlation daily waveform data inter-stations. The daily waveform of inter-stations cross correlation result was stacked then used Gaussian bandpass filter operation with period centre 5 s. Result of signal stacking is showed as in Fig. 3

To identify and eliminate unfavourable results in order to obtain reliable tomographic results used the Signal to Noise Ratio (SNR) criteria to select the data. Signal with SNR > 4 is selected for next read arrival time of its Rayleigh wave estimation.

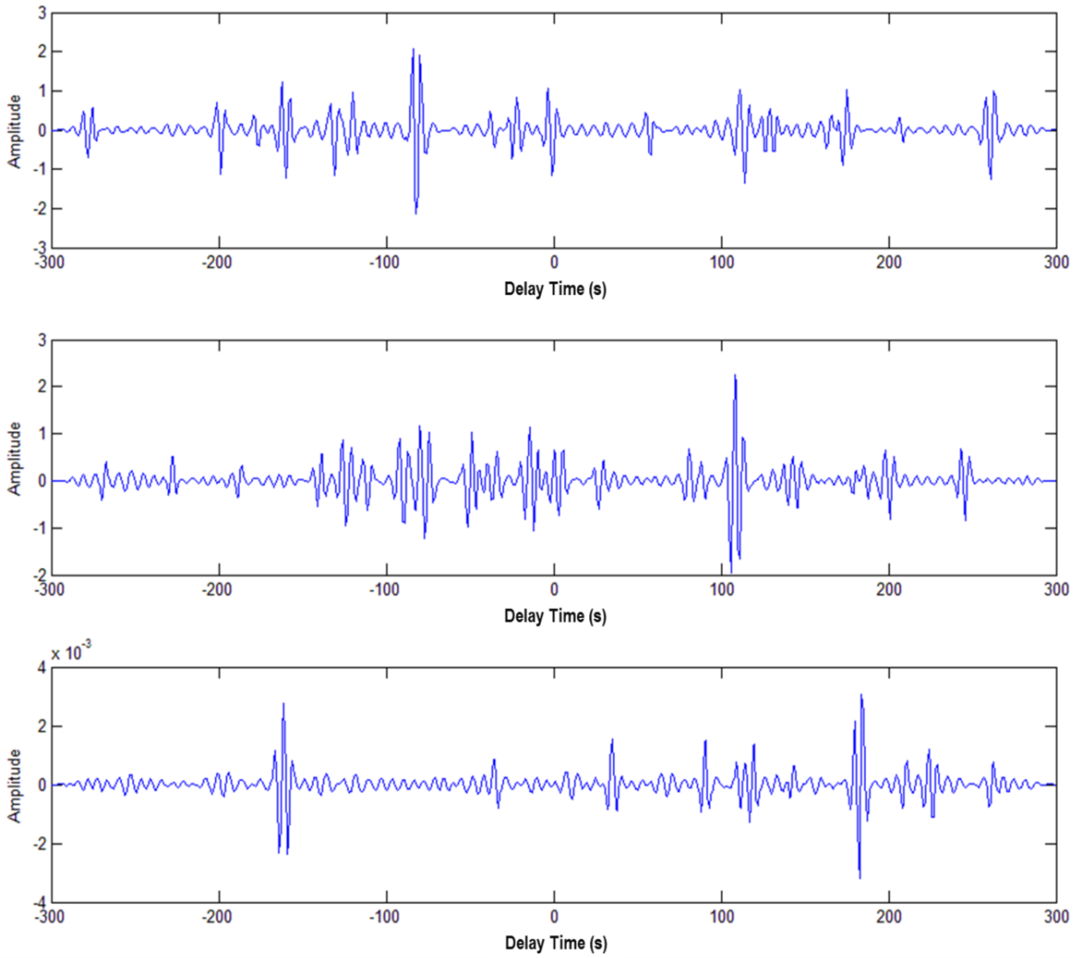


Fig 3: Results of stacking seismic signal

A. Resolution Test

The tomographic resolution test was performed by making a homogeneous initial velocity model of 3 km/s. To make the synthesis travel time data, the checkerboard model was determined first, it is the model with the positive and negative speeds of the initial speed values arranged alternately. The synthesis travel time data were made based on the model and then added noise gaussian to the data.

The inversion process was performed on the synthesis data to test how well the source and receiver geometry are able to properly represent the research area. A region with sufficient number of ray path will provide a final model similar to the original checkerboard model, while region with low ray path amounts will produce a polishing effect.

B. Period 5 s

Rayleigh wave velocity map on 5 s period is sensitive to upper crust with depth reaching 8 km [13]. Low-velocity zones of 2.7 - 2.9 km/s were clearly identified east-west in the southtern part of east Java (Fig. 4) associated with a quarterly quartz volcano and inter-quarterly volcanic plains dominating much of eastern Java. East Java has a Tertiary sedimentary basin that is 6 km [14]. The center of the basin is located in the middle of East Java (around Sragen, Karanganyar, Ngawi, Madiun, Nganjuk, Kediri, Bojonegoro, Jombang and Mojokerto) that has a direction to the west-east.

The territory of Central Java is generally still in an area where the resolution of the map is well received. The area has a relatively low Rayleigh Wave velocity value in the south and rises to the north. It is difficult to explain the relation between the variation of the Rayleigh wave velocity value with the physiographic condition of the area given the complexity of the existing lithology composition while the existing resolution is still relatively large.

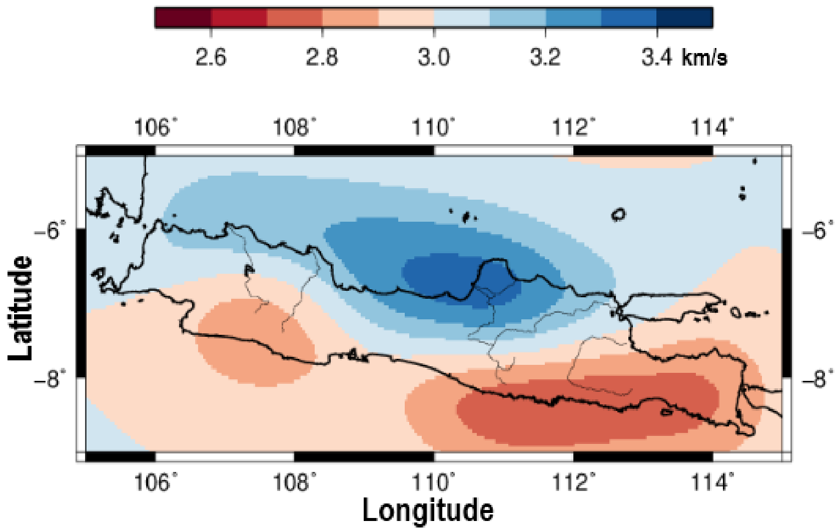
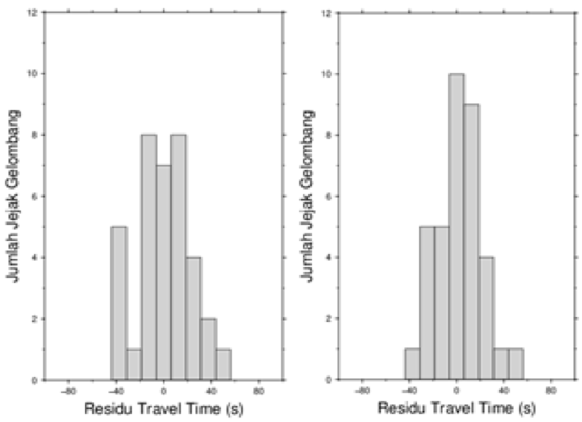


Fig. 4: Rayleigh wave group velocity map with period 5 s



(a) (b)

Fig. 5:Histogram of residual travel time for early (a) and late (b) tomography models

As shown in fig. 4, for the region of West Java, the velocity of Rayleigh wave group also graded from low to high from the south to the north. The low anomaly in West Java corresponds to the location of the volcano zone of the quarter and Bandung zone which is a depression where most of these zones are filled with young volcanic deposits of products from surrounding volcanoes. The velocity value increases to the north of the zone with Bogor zone formed from deep sea sedimentary rocks with older ages in the Pliocene-Pleistocene period. Histogram of residual travel time for early and late tomography models is shown in Fig. 5

IV. CONCLUSION

Rayleigh wave velocity modelling result in Java Island using ambient noise tomography for period 5 s produces the distribution of low speed zones corresponding to the distribution of volcanoes and quarterly quartz volcanoes in Java Island

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REFERENCES

[1] M. Campillo, "Ambient Noise Imaging," 2004.
[2] Y. Yang, M. H. Ritzwoller, F.-C. Lin, M. P. Moschetti, dan N. M. Shapiro, "Structure of the crust and uppermost mantle beneath the western United States revealed by ambient noise and earthquake tomography," *J. Geophys. Res.*, vol. 113, 2008.
[3] K. . Cho, R. . Hermann, C. J. d Ammon, dan K. Lee, "Imaging the crust of Korean Peninsula by surface wave tomography," 2006.
[4] H. Yao, R. D. van der Hilst, dan M. V. de Hoop, "Surface-wave Array Tomography in SE Tibet from Ambient Seismic Noise and Two-station Analysis: I - Phase velocity dispersion and maps," 2006.
[5] Y. Yang, M. . Ritzwoller, A. . Levshin, dan N. M. Shapiro, "Ambient noise Rayleigh wave tomography across Europe," *Geophys. J. Int*, vol. 168, hal. 259–274., 2007.
[6] F. Lin, M. . Ritzwoller, dan N. . Shapiro, "Is Ambient Noise Tomography Across Ocean Basins Possible?," *Geophys. Res. Lett.*, vol. Vol 33, 2006.
[7] E. Saygin dan B. Kennet, "Ambient Seismic Noise Tomography of Australian Continent Research School of Earth Science, The Australian National University.," 2008.
[8] L. Stehly, "Toward improving ambient noise tomography using simultaneously curvalet denoising filters and SEM simulations of seismic ambient noise. Internal geophysics (Physics of Earth's interior).," *Intern. Geophys. (Physics Earth's Inter.*, 2011.
[9] S. Widyantoro, "Seismicity and Subduction Zone Model with High Resolution. Seminars and Exhibitions of HAKI (in Indonesian)," 2008.
[10] S. Munadi, *Know the LPL Seismic Tomography, Lemigas, Indonesia (in Indonesian)*. Lemigas, Indonesia, 1992.
[11] L. Stehly, "Stehly L. et all. 2011. Short Period Surface Wave Dispersion From Ambient Noise Tomography in Western China," 2011.
[12] R. . Stewart, "Tomographic inversion via the conjugate gradient method," *Geophysics*, vol. 52, hal. 179–185.
[13] H. Nicolson, A. Curtis, B. Baptie, dan E. Galetti, "Seismic Interferometry and Ambient Noise Tomography in the British Isles," in *Proceedings of the Geologists' Association*, 2011.
[14] M. A. Hasan dan M. . Nurwidianto, "Spreading Estimation of East Java Basin Sediment Using Gravity Method," 2008.