Ambient Noise Tomography of Merapi Complex, Central Java, Indonesia: A Preliminary Result

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Abstract. Mt. Merapi is one of the most active and hazardous volcanoes not only in Indonesia but also in the world. Having a height of about 2968 meter above sea level it contains an active lava dome, which regularly produces pyroclastic flows and is categorized as a stratovolcano. It erupts on average every 2-5 years, in which thousands of people live on the flanks of the volcano. The last eruption occurred on 26 October 2010 and after the large eruption in 2010 the characteristic of Mt. Merapi was changed. Due to its uniquess, Merapi is closely monitored by the many geoscientists, particularly through volcanoanalogue surveys. This study is concerned with the application of ambient noise tomography (ANT) to create Rayleigh wave group velocity maps around Mt. Merapi. The continuous data set is taken from the DOMERAPI project, which consists of temporary seismic array of 40 broadband seismometers for approximately ten months. The resulting group velocity maps of Rayleigh wave show an anomaly pattern that agrees with previous geological and geophysical study results. A pronounced, positive anomaly is clearly imaged with direction about 152°N beneath Mt. Merapi through to Mt. Merbabu. In addition, negative anomalies are observed in its east and west flanks.

Keywords: Volcano, Ambient Noise, Tomography, Rayleigh Wave

1. Introduction

In the last decade, a number of researches have been developed for creating more effective methodologies to be applied in seismological studies to cope with the recent regulations which addressing the assessment of seismic hazard. Since the distribution of earthquakes is poor and almost impossible to controlled, seismologist need another tools to overcome the lack of earthquake data in the recording so that we still can produce a high resolution images in insufficient path coverage seismically inactive regions. On the other hand, seismometer will always contain noise in the recording with or without the presence of earthquake signal. Noise is conventionally described as disturbance in the seismogram which usually is removed by seismologist for not contain any useful
information. It can come from the instrumentation itself or mostly from ambient noise vibration. Ambient noise can take a wide variety of forms, for example, it might come from urban dwellers, rural regions, oceanic activities or even atmospheric activities. This ambient noise will be recorded by seismometer as a surface waves. There are two kinds of surface waves; the first ones is Rayleigh waves, the wave whose induces an elliptical motion with the amplitude exponentially decreases by increasing in depth. Such elliptical motion is the result of the superposition of the vertical and radial components. The other surface waves called Love waves are somehow simpler because they move only on the horizontal plane, transversally with respect to the direction of propagation.

Using basic principle of seismic interferometry (SI), Green’s function from surface waves can be extracted between two stations in different location by long term correlations of ambient seismic noise recording. Now days, surface wave tomography based on cross-correlation of ambient seismic noise has been applied successfully at local and regional scales. This new technique promises significant improvements in seismology especially in obtaining high resolution and accuracy of crustal and upper mantel images without needing the presence of any earthquake signals. This paper will merely describe some preliminary results and analysis on applying tomography using seismic ambient noise data in Merapi volcano as one of the most active volcano in Indonesia. Based on authorized record, this volcano has already erupted 33 times with a short rest period from about 1 to 6 year.

2. Geology Regional

Merapi volcano is an almost persistently active basalt to basaltic andesite volcano in Central Java, Indonesia. It is one of the world’s most active and dangerous volcanoes in Indonesia. According to Van Bemmelen [21], the area around Merapi volcano consist of two different materials; the basic material is low density alluvial, whereas the volcanoes themselves consist of denser material from Holocene volcanic material.

![Map of volcanoes surrounding Merapi complex. This picture shows that Merapi volcano is bounded by two volcanic alignments intersections.](image)

Merapi volcano formed on Late Pleistocene – Early Holocene period, above the Eurasia – Indo-Australia tectonic plates subduction zone and is bounded by two main volcanic alignments intersections, Ungaran – Telomoyo – Merbabu - Merapi (MMTU) and Lawu – Merapi – Sumbing –
Sindoro – Slamet (SSSML) (figure 1) [1]. MMTU volcanoes is an example of the double-chain volcanic arc, phenomenon of the existence of two or more volcanoes across the arc and its volcanoes can be divided into the trench-side and back-arc side volcanoes. The back-arc side volcanoes of Slamet (still active) and Ungaran (dormant) are located about 210 – 225 km above the slab while the vertical distance of Merapi volcano from the slab is about 175 km. It is clearly demonstrated that the vertical distance between each volcano and subducted slab increases constantly from the trench side or in this case Merapi volcano in the south towards back-arc side in the north. Based on radiometric data from Kohno et al. [6], the volcanism along MMTU double volcanic chain seems to occur during the Quarternary period up to now with Ungaran volcano is the oldest followed by the Telomoyo, Merbabu, and Merapi as the youngest and also the only active volcano in MMTU section. While in MMTU only have Merapi as the active volcano, all the volcanoes in SSSML is still classified as active volcanoes.

3. Data Sets and Processing
We used DOMERAPI array which continuously recording for about ten months from October 2013 to July 2014. There are 42 three component broadband seismometers, placed surrounding Merapi and Merbabu volcanoes (figure 2). For this preliminary result, we obtain the Green’s function from vertical component only which representing Rayleigh wave. Also this study used ambient noise from microseism activity generated by oceanic waves with frequency ranges about 0.03 – 0.3 Hz consist of Single Frequency Microseism (0.03 – 0.1 Hz) and Double Frequency Microseism (0.1 – 0.3 Hz).

![Figure 2](image_url)

**Figure 2.** The area inside the black square is our study area with stations distribution location in the inset.

This study followed the method published by Bensen et al. [2] to produce the Green’s function from cross correlating data between two different stations. There are some routine data processing which aim to improve the data quality. It basically contains some signal analysis and processing to obscure the earthquake signal and enhance the noise. The first step is removing mean, followed by removing trend, and some normalization technique. The most important part in routine processing is
doing the time domain normalization. We performed one bit normalization as tools to accentuate the noise. We also applied spectral whitening as additional method. The next step is the main processing of seismic ambient noise, it is cross correlation and stacking. We performed daily cross correlation and then stacked it over ten months. There are 770 Green’s function as a results with two sides time function consist of positive (causal) and negative (acausal) time lags.

Through cross correlated the data from relatively south seismometers to relatively north ones, we obtained unique Green’s functions in which acausal part mostly being the dominant part in Green’s function results (figure 3). It indicating that Rayleigh waves are dominantly comes from the north of the Merapi volcano. Then we measured the dispersion curves from acausal Green’s function in all station pairs using multiple filtering technique which is introduced by Dziewonski et al. [4] to produce the group velocity of various frequencies in every station pairs. According to Bensen et al. [2], we found that a reliable dispersion measurement at a certain period correspond to its interstation distance (Δ in km) it should at least 3 wavelength (λ) or the maximum cut off period is in about 11.1 second with 1.55 kms-1 as phase speed estimation. For the tomographic inversion we integrated fast marching method and subspace inversion provided by Rawlinson (2005). The detailed is given in Rawlinson & Sambridge [12].

4. Results and Discussion

Tomography map from group velocity shown two interesting structures as seen in figure 4. The first part is the relatively high group velocity anomaly right beneath Merapi and Merbabu volcano, this structure linearly connecting Merbabu volcano to Merapi volcano with direction about 152°N. The second part comes from the wide relatively low group velocity anomaly in about southwest of Merapi volcano. Based on previous study, we then compared and analyzed these two anomalies corresponding with the other Merapi volcano studies. Compared with studies from Koulakov et al. [7] and Zulfakriza et al. [19], the high group velocity anomaly is not clearly emerge since they study regional zone. However, Koulakov have noted that even Merapi volcano lies in strong low velocity anomaly, MLA (Merapi Lawu Anomaly) but the volcanoes themselves appear to be located above relatively higher-velocity patterns [7].
Figure 4. Group velocity tomography result for 4 (a) and 6 (b) period. Interpretation only focusing inside the red lines which is having the best resolution image from checkerboard test. It consist of two main bodies representing high velocity anomaly and low velocity anomaly.

More similar results came from Bouguer gravity map by Tiede et al. [16]. Apart from Bouguer anomaly gravity maps, Tiede et al. [16] also provides the 3 dimensional modelling for high and low gravity anomaly separately. From their results, we can observe a number of similarities in both interesting structures of this study. The high density structures with northwest – southeast direction which lies along Telomoyo – Merbabu – Merapi volcanoes and 2 – 7 km depth surrounded by lower gravity is directly proportional with the group velocity anomaly from this study. This arc structure with high density and high group velocity anomaly showing the NS striking transverse fault zone that is mentioned by Van Bemmelen [17]. It is underlines the history of volcanic origin in which shows the older basaltic lavas derived from subduction’s partial melts passing the fault zones, and through the cooling and solidification so that it’s becoming intrusive complex. Moreover the low group velocity anomaly in the southwest of Merapi volcano not only related with the low density structure from Tiede et al., [16] but it also coincidence with low resistivity structure from magnetotelluric method provided by Müller and Haak [9]. This anomaly structure indicates a potential location of Merapi volcano’s magma chamber.

5. Conclusions

We used ten months of seismic noise data recorded by DOMERAPI seismic array to extract the Rayleigh wave Green’s function. This Green’s function is used to perform a Rayleigh waves tomography around Merapi complex. This tomography ambient noise method successfully improved the resolution of the the shallow depth right beneath Merapi complex in which have less seismicity activity compared to subduction’s activity in the southern part of Java.

Tomographic inversion shows a coincidence results with some previous studies. There is an high group velocity anomaly and high density anomaly linearly running direction about 152°N beneath Merapi complex which is indicated as old basaltic lava, intrusively starting from higher anomaly in NW to the SE alongside the transverse faults. Furthermore there is an indication of magma chamber in the southwest flank of Merapi volcano according to its properties such as low group velocity, low density and also low resistivity anomalies.

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