Ambient Seismic Noise Cross-correlation of Ambon Island and Surrounding Area, Eastern Indonesia: Preliminary Result

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Abstract. The island of Ambon lies on complex tectonics, part of Banda Arc which is driven by the Australia – Eurasia collision. Historical earthquake data show that an earthquake resulting the greatest tsunami in Indonesia had occurred at Ambon Island. On 26 September 2019, Ambon was shaken by an M 6.5 earthquake at a depth of 10 km (BMKG). In this study, we use ambient noise data from 11 temporary stations deployed by ITB and 4 permanent stations owned BMKG which are recorded from October until December 2019. Here, we purely use the vertical component of seismogram to retrieve the Empirical Green’s Function of Rayleigh waves. Cross-correlations were obtained from the daily data series and stacked the day-by-day cross-correlation data into one inter-station cross-correlation. The Empirical Green’s Function is seen at the band period 1-15 s. As a part of our study, we analyze the Green’s Function with frequency-time analysis (FTAN) to get Rayleigh wave group velocity. The group velocity of Rayleigh waves varies from 1.04 km/s – 3.75 km/s. Low group velocity might be indicated the presence of sediment or volcanic deposits and high group velocity might be indicated metamorphic rocks. The result of this study might give a finer velocity model of the shallow crustal beneath Ambon Island and the surrounding area.

Keywords: Ambon, tomography, ANT
1. Introduction
Ambon Island, part of Banda Arc lies on a complex and unique convergence plates zone which is producing a high heterogeneity structure and seismically active area that has been experiencing great earthquakes and tsunamis [1,2,3]. Based on the historical earthquake, Ambon Island has been hit by large earthquakes and several of them were followed by tsunamis. One of the biggest tsunamis in Indonesia was documented at Ambon Island that was triggered by an earthquake [4]. In recent years, another large earthquake, the M 6.5 earthquake hit Ambon Island on 26 September 2019, causing many injuries and buildings damaged. The mainshock located between Ambon and Haruku Islands at the depth of 10 km and could be classified into a shallow earthquake with a strike-slip source mechanism (BMKG). The mainshock M 6.5 followed by a dozen aftershock for more than 2 months with the aftershocks pattern trending almost in the N-S direction. The biggest aftershock occurred in Ambon Island with a magnitude of 5.1 located 10 km from the mainshock [5]. However, according to the magnitude and number of events, the aftershock decreased with time period. Although the aftershock dominated with small magnitude, it could be felt by civilization due to the hypocenter is in shallow depth.

The interesting phenomena lead to ITB, BMKG, and BNPB deployed temporary stations in Ambon Island and surrounding area to learn about the phenomena for future disaster mitigation. Recently, the application of ambient noise has emerged to inspect closely subsurface of earth. This method utilizes the ambient noise for estimating the Green’s function (EGF) by calculating the cross-correlation between two seismic stations as if one station acts as a virtual source and another station acts as a receiver [6].

Ambient noise to obtain shallow subsurface structure, that based on cross-correlation, has been successfully applied in several places in Indonesia. There are in the volcanic region of Toba Lake [7] and Agung – Batur volcanoes [8], complex tectonic of continent collision in Banda Arc [9], and Java Island: Western part of Java [10, 11,12], Central Java [13], Eastern part of Java [14].

In this paper, we describe our preliminary results of cross-correlation process of ambient noise data and frequency-time analysis (FTAN) process to procure the dispersion curve corelated of the group velocity and tried to correlate with geological subsurface. We hope this study could be used to understand the earth structure by analyzing the group velocity of Ambon Island and surrounding island.

![Figure 1. Distribution of temporary seismic station from the ITB temporary network (red inverted triangles) and permanent seismic station from the BMKG network (yellow inverted triangles).](image)

2. Data and Method
In this study, we use 11 temporary stations from the ITB network and 4 permanent stations from the BMKG network supported by BNPB. The temporary stations were installed from October to December 2019, but not all stations have the same recording time because the battery was running out. Figure 1 shows the deployment of seismic stations at Ambon Island and its surrounding. In this study, we focused on the vertical component to infer the EGFs of Rayleigh waves to obtain the group velocity.
Data processing, we follow common procedures to get empirical green functions (EGF) [15]. The process contains single station preparation and preprocessing, cross-correlation and stacking, and measurement of the group velocity. We merged data from 10 minutes to a daily data waveform and converted the data from MSEED to SAC. In this study, we used different type of seismometers, so we have to apply instrument correction to the data. The preprocessing data contains de-trending, de-meaning, and bandpass filtering to accentuate the ambient noise signal. The data filtered in the period band 1 – 15 s and resampled to 20 Hz. We performed temporal normalization and spectral whitening in 1-hour segment data prior to the cross-correlation process to suppress the effect of earthquake signals. Second, the cross-correlation process performed in the frequency domain with lag time -100 s (acausal part) to 100 s (causal part) and set lag time – 60 s to 60 s to arrange all of EGF. To calculate cross-correlation, we used a package from [16], and this process yields \( n(n-1)/2 \) stations pair, where \( n \) is the stations that we used. The number of cross-correlation in this study is 105 from the availability of the data. After measuring daily cross-correlation, we stacked the daily cross-correlation by using the linear stacking method for all-day recorded if the data in both stations are available. The stacking process will increase the coherency of the EGF signal and increase the signal to noise ratio (SNR) (shown in figure 2). Third, the measurement of the group velocity of Rayleigh waves was obtained based on frequency-time analysis (FTAN). We manually picked the EGFs and set the SNR greater than 3 to get good dispersion curves. SNR is calculated using the ratio of maximum amplitude of envelope around the frequency signal length and the mean amplitude envelope after the signal window. From all the 105 data we have only extracted 52 good quality dispersion curves.

![Figure 2. The daily EGF vertical component from station MA07 – MA11 (black lines) and the stacked EGF from the daily cross-correlation result (red line).](image)

3. Result and Discussion
We arrange all of the EGFs from cross correlation as interstation distant function. Here, we assume that EGF is a representation from medium passed by seismic waves between both of stations. We can see that EGF cross correlation in figure 3 (left) has a reflection pattern in both causal and acausal sides. Anyway, the “V” pattern not clearly seen, but it has a little pattern shaped “V”. The result was probably affected by the sea waves around the stations deployment.

The group velocity of fundamental mode of Rayleigh waves was obtained from cross-correlations and analysis the time-frequency of ambient noise data. Fundamental mode of Rayleigh waves at small periods (high frequencies) are sensitive to the physical properties at the shallow structures and high periods (low frequencies) at the deep structures. The dispersion curves were obtained from all possible EGF that have SNR greater than 3 shown in figure 3. We use a method from Yao [17] to determine group velocity of fundamental mode Rayleigh waves. Figure 3 (right) shows the dispersion curved that has been extracted from the EGFs result. The group velocity in the study area varies from 1.33 km/s – 3.75 km/s at the band period of 0.1 s – 6 s (most energetic Rayleigh waves). The low group velocity
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might be related to the sediment layer that can amplify the seismic wave propagating from the earthquake. Then, the high velocity might be correlated with metamorphic rocks that dispersed in the study area.

Figure 3. Empirical Green Function (EFG) cross correlation filtered bandpass in 1 – 15 s with SNR greater than 3 (left). The dispersion curves of Rayleigh waves that can be extracted from EFG with SNR greater than 3 (right).

4. Conclusions
In this preliminary study, we have conducted 2 months ambient noise data from 15 stations that supported ITB, BNPB, and BMKG to obtain group velocity. We obtained the group velocity of the Rayleigh wave using cross-correlation of the vertical component of ambient noise data in Ambon Island and surrounding. The EGF is seen at period band 1 – 15 s and from the EGF’s arranged as interstation distant function (“V” shape pattern) show that the distribution of ambient noise source might be distributed randomly from the surrounding stations (close to sea). The dispersion curves, that have SNR greater than 3, is ~49 percent.

The group velocity varies from 1.04 km/s – 3.75 km/s at band period 0.1 s – 6 s (most energetic Rayleigh waves). Low group velocity indicated the existence of a sediment layer and high group velocity indicated metamorphic rocks that needed further study to know better about the distribution of the rock or layer types in the study area.

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References
[1] J M Pownall, R Hall, and I M Watkinson. 2013. Solid Earth. 4 277 – 314
[2] J M Pownall, R Hall, R A Armstrong, and M A Forster. 2014. Geology. 42 279 – 282
[3] A Spicak, R Mattrjkova, and I Vanek. 2013. J. Asian Earth Sci. 64 1 – 13
[4] D Sahara, A D Nugraha, A Muhari, A A Rusdin, S Rosali, A Priyono, Z Zulfakriza, S Widiyantoro, N T Puspito, A Rietbrock, A Lesmana, D Kusumawati, A Ardianto, A W Baskara, YHalauwet, H A Shiddiqi, M T Rafie, R Pradisti, P W Mozefg, M Z Tuakia, E Elly. 2021. Techtonopycics. 799
[5] I R Pranantyo and P R Cummins. 2019. Pure Appl. Geophysics. DOI:10.1007/s00024-019-02390
[6] N M Shapiro, M Campillo, L Stehly, and M H Ritzwoller. 2005. Science. 307 1615 – 1618
[7] J Stankiewicz, T Ryberg, C Haberland, Fauzi, and D Natawijaya. 2010. Geophysical Research Letters. 37 1-5
[8] Zulfakriza, A D Nugraha, S Widiyantoro, P R Cummins, D P Sahara, S Rosalia, A Priyono, Kasbani, D K Syahbana, I C Priambodo, Martanto, Ardianto, Y M Husni, A Lesmana, D kusumawati, and B S Prabowo. 2020. Front. Earth Sci. 8 1 - 11

[9] R W Porrit, M S Miller, L J O’Driscoll, C W Harris, N Roosmawati, LT da Costa. 2016. Earth and Planetary Science Latters. 449 246 – 258

[10] E Saygin, P R Cummins, A Cipta, R Hawkins, R Pandhu, J Murjaya, Masturyono, M Irsyam, S Widiyantoro, and B L N Kennet. 2016. Geophysical Journal International. 204 918 – 931

[11] B Pranata, T Yudistira, S Widiyantoro, B Brahmantyo, P R Cummins, and E Saygin. 2019. Geophysical Journal International. 220 1045 – 1054

[12] S Rosalia, P R Cummins, S Widiyantoro, T Yudistira, A D Nugraha, and R Hawkins. 2020. Geophysical Journal International. 220 1260 - 1274

[13] Zulfakriza, E Saygin, P R Cummins, S Widiyantoro, and A D Nugraha. 2014. Geophysical Journal International. 197 630 – 635

[14] A A Martha, P R Cummins, E Saygin, amd S Widiyantoro. 2017. Geosci. Lett. 4 1 – 12

[15] G D Bensen, M H Ritzwoller, M P Barmin, A L Levshin, F Lin, M P Moschetti, N M Shapiro, and Y Yang. 2007. Geophysical Journal International. 169 1239 – 1260

[16] H Yao, C Beghein, and V D Hilst. 2008. Geophysical Journal International. 173 205 – 219

[17] H Yao, P Gouedard, J A Collins, J J McGuire, and V D Hilts. 2011. Comptes Rendus Geoscience. 343 571 – 583