Seismic noise synthetic from shallow 1D velocity model for horizontal to vertical spectral ratio measurement

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Abstract. Site effect and soil properties beneath a station can be investigated from the curve of horizontal to vertical spectral ratio (H/V spectral ratio). H/V spectral ratio curve is estimated from ambient vibration or seismic noise recorded at long enough period time. In this study, we created synthetic seismogram of ambient vibration or seismic noise from 1D velocity model in Tangerang, Indonesia. 1D velocity model consists of two layers of soil and a bedrock. The velocity model was obtained from the inversion Rayleigh ellipticity using time frequency analysis. The obtained synthetic seismogram of noise then was used to calculate H/V spectral ratio curve model. We compared the calculated H/V spectral ratio curve and the observed H/V spectral ratio. There is a different in H/V spectral ratio curve maximum amplitude ($A_0$). The difference might be related to the velocity model used in this modelling that are not constrained by borehole data.

1. Introduction
Indonesia is located along plate boundary of Eurasia and Indo-Australian Plates. Consequences of this tectonic setting cause earthquake occurrence and presence of volcanoes. Java Island lies north of Java trench, which is a subduction zone between Eurasia and Indo-Australian Plates. In Java, several large earthquakes occurred due to the tectonic activity such as 2007 $M_w$ 7.7 Pangandaran and 2009 $M_w$ 7.0 West Java earthquakes. Due to large population in this region, earthquake mitigation has become priority in the government policy to reduce the hazard risk.

In earthquake hazard mitigation study, site amplification factor is one of important parameters in describing seismic risk in one region or area. The parameter may represent the ground shaking due to an earthquake. The ground shaking depends not only on earthquake magnitude but also the site conditions [1, 2]. Study of site response may give information on the site amplification factor. One of the methods to estimate site response and also soil properties is horizontal to vertical spectral ratio (H/V spectral ratio) method [3]. The method use records of ambient vibration or seismic noise from one station. The source of ambient vibration may come from natural sources or human activities, and it might consist of body and surface waves. H/V spectral ratio peak may represent minimum amplification factor and resonance frequency of the site [4, 5].

Several studies have shown that H/V spectral ratio curve could be used to estimate the ellipticity of fundamental mode of Rayleigh wave [6, 7]. It is suggested that H/V spectral ratio peak may represent an ellipticity peak, which is estimated between peak frequency of resonance and first minimum at...
higher frequency [7]. These ideas suggested that H/V spectral ratio curve around its maximum peak can be used to determine shallow seismic velocity profile. However, recent studies proposed that H/V spectral ratio curve may not only be contributed from Rayleigh wave but also from Love wave [e.g. 8]. One of the methods to estimate Rayleigh ellipticity is using time-frequency analysis and a wavelet transform (HVTFA) [9]. We have applied HVTFA to continuous seismic records in Tangerang, to estimate the H/V spectral ratio and Rayleigh ellipticity [10]. We then inverted the Rayleigh ellipticity to obtain shallow subsurface structure. However, a trade-off between layer thickness and its velocity might be occurred for this inversion. To reduce such trade-off we may apply information obtained from borehole data, which is not available to us, to constrain these parameters.

In this study, we applied the obtained seismic velocity model from the calculated Rayleigh ellipticity to compare the observed H/V spectral ratio and compare to the numerical H/V spectral ratio. We carried out numerical analysis of synthetic noise seismogram from the obtained velocity model. We calculated H/V spectral ratio from the synthetic seismogram to obtain an estimated amplification factor and frequency resonance from a site in Tangerang, Indonesia.

2. Data Observation and Methods

Table 1 shows the velocity model beneath the station to create synthetic seismogram. A medium model was used for numerical domain with a receiver location is at the center of the domain (figure 1). A total of 5,000 random sources were generated within the domain to excite a source function. A source function or force with three component of north, east and down directions was excited for each random source. Synthetic seismogram was sampled at 0.01 s with a total length of about 900 s. We stacked synthetic seismograms from each random source to obtain an estimated ambient vibration. We applied a code from Herrmann for this numerical study [11].

![Figure 1. A schematic illustration of random sources location. Triangle and circles represent a seismic station and sources, respectively.](image)

| Thickness (m) | $Vp$ (km/s) | $Vs$ (km/s) | Density (g/cc) |
|---------------|-------------|-------------|----------------|
| 100           | 0.6         | 0.4         | 1.9            |
| Half space    | 2.1         | 1           | 2.5            |
3. Results and Discussion

Figure 2 shows synthetic seismogram of ambient vibration or noise for a total length of 15 min and its spectral amplitude for each component. Three component seismograms were generated from the numerical analysis. It shows the seismograms contain not only data with noise level but also with large peaks or amplitudes. Figure 2 (a) shows each window length for the calculation of H/V spectral ratio. Figure 2 (b) shows spectral amplitude for each component of synthetic seismograms. We calculated H/V spectral ratio from the synthetic seismogram using Geopsy. We removed spike amplitudes using STA/LTA anti-trigger algorithm. Spectra from each component were calculated with 25 s window length with 5% cosine taper. Spectra from horizontal components (N and E) were averaged, and we calculated H/V spectral ratio for each window. H/V spectral ratio was calculated in the frequency of 0.5 – 10 Hz.

![Figure 2. (a) Synthetic seismogram of ambient vibration or noise. Colours represent window length used to calculate spectra for each component. (b) Spectral amplitude of synthetic seismogram.](image-url)
Figure 3. Calculated H/V spectral ratio curve from the ambient vibration synthetic (black solid line). Black dashed represent the standard deviation and red dashed line represent observed H/V spectral ratio at a station in Tangerang (TNG), Indonesia.

Figure 3 shows the calculated H/V spectral ratio curve from the synthetic seismogram. We compared calculated H/V spectral ratio from synthetic seismogram and observed seismogram from a seismic station in Tangerang, Indonesia. We observed that peak amplitude ($A_0$), which represent amplification factor of a site synthetic seismogram is almost same (~2.0) with the observed $A_0$. The obtained amplification factor from the H/V spectral ratio might not give a true amplification factor [12, 13]. However, it might suggest the lower estimation of the true amplification [14]. We estimated that peak frequency ($f_0$) or resonance frequency of a site for H/V spectral ratio from synthetic seismogram is 0.88 Hz while for $f_0$ from observed seismogram is about 0.82 Hz.

We suggest that generally the calculated H/V spectral ratio from our synthetic seismogram agrees well with the observed H/V spectral ratio at the station of TNG. Clear peak amplitude of H/V spectral ratio may indicate relatively strong impedance contrast between soft layer and hard rock as suggested by the velocity model used in this study. Station TNG sits on top of alluvium layer. In this area, the depositional layer may reach to depth of about 100 m as suggested by Turkandi et al. [15]. Previous study has carried out experiment on the effect of alluvium thickness to the measured H/V spectral ratio. For example, Teves-Costa et al. [16] estimated H/V spectral ratio on the alluvium layer sitting on the top of a hard rock. They suggested that the peak amplitude might decrease with an increase of alluvium layer.

4. Conclusions
We carried out numerical analysis of ambient vibration synthetic seismograms using one-dimensional velocity model. Velocity model used in this study is obtained from the inversion of Rayleigh ellipticity. We computed H/V spectral ratio from the synthetic seismograms and compared to the observed H/V spectral ratio curve. In general, the obtained $A_0$ and $f_0$ is comparable to the observed values from Tangerang, Indonesia.

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