**Horizontal-to-vertical spectral ratio of ambient noise vibrations for local site effects estimation in ITERA**

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**Abstract.** Local site effects related to the local geology can influence the damage caused by an earthquake, by amplifying or de-amplifying the ground motion. To characterize the site effects in a local area, the natural frequency and the amplification factors can be estimated by performing Horizontal-to-Spectral Ratio of the ambient noise vibrations recorded. This method is applied by recording the ambient noise in 1.5x1.5 km² ITERA campus area, deploying 11 points of measurements originally with 500 meters in spacing and 4 additional points with 125 meters in distance to the westernmost points. The recording of 45 to 60 minutes for each point has been done to accommodate the lowest possible natural frequency we may obtain. However, some data contain too high amount of noise that we have to eliminate them. The HVSR estimation shows that there are two predominant frequency, F₀ and F₁ F₀. The west-south area of ITERA tends to be more slightly vulnerable than the north and east area. The amplification factors Aᵣ are varied from 2.5 to 9 and is considered as the low bound of the real amplification factor.

**Keywords:** microtremor, HVSR, microzonation, natural frequency, site amplification

1. **Introduction**

Infrastructure catastrophic damage caused by an earthquake is a result of the ground shaking amplified by the local site effect and weak construction design. The unproperly study of local geological condition gives minimum information needed to build the earthquake resistant structures, leading to many severe damages on buildings and endanger people who lives in that area whenever earthquakes occur. To minimize the destruction of earthquake disaster, it is important to do analysis procedure in seismic risk mitigation. One of the procedures is to characterize the site effect in order to understand the level of earthquake amplification in one particular area [1].

There are several ways of estimating the site effect characterisation, such as from recordings either from earthquakes, explosions, or numerical simulations but those methods are not easily applicable and expensive [2]. Recording from earthquakes are not efficiently applicable in the low seismicity areas, due to the lack of sufficient data. In this case, the alternative way is to record the microtremor signal from human-generated ambient seismic noise to estimate the natural frequency and the amplification factor from horizontal to vertical spectral ratio (HVSR).

Some seismologists related HVSR of microtremor with HVSR of Rayleigh wave since the characteristic are similar and because ambient noise mostly consists of surface waves [3]. However, Nogoshi and Igarashi [4] and Ohta [5] pointed that no energy of Rayleigh wave exists in the peak frequency of HVSR. Therefore, the frequency peak can be associated with the multiple reflection of SH waves. On the soft sediment layer, the multiple reflection of SH waves will affect the horizontal motion of sediment layer causing the movement becomes larger than vertical motion. On the other hand, the horizontal movement of compact bed rock is observed equal with the vertical motion [6].

2. **Horizontal to Vertical Spectral Ratio (HVSR)**

Nakamura [7] [6] defines microtremor as consisted as Rayleigh wave and body waves. If the typical geological structure of a sedimentary basin is shown by Figure 1, then the horizontal (Hᵥ) and vertical spectra (Vᵥ) on the surface ground of the basin is written as follows,

\[ Hᵥ = Aᵣ * Hₑ + Hₛ \]

\[ Vᵥ = Aᵣ * Vₑ + Vₛ \]

1)
The amplification factor of horizontal ($T_h$) and vertical ($T_v$) motion of sedimentary ground are the ratio between the frequency spectra of the surface and the basement rock. Here in the equation 3 and 4, $A_h$ and $A_v$ represent horizontal and vertical amplification factor for incident body waves, $H_b$ and $V_b$ denote horizontal and vertical spectra of the basement ground, and $H_s$ and $V_s$ correspond to the spectra of horizontal and vertical directions of Rayleigh waves. For the sedimentary layer, when there is no effect of Rayleigh wave, the horizontal motion can receive a large amplification while the vertical motion stays unamplified. This is caused by the multiple reflection of SH waves in the sedimentary layer. In this case, the value of $V_f$ becomes equal to $V_b$. When Rayleigh wave affects the motion at the surface, then $V_f$ will be much larger than $V_b$, and the amplification factor at the surface can be written as equation 3.

$$T_h = \frac{H_f}{H_b}, \quad T_v = \frac{V_b}{H_b}$$

$$T_h = \frac{T_h}{T_v} = \frac{H_f}{V_f} = \frac{H_b}{V_b} = \frac{[A_h + H_s]}{[A_v + V_s]}$$

where

$$QTS = \frac{H_f}{V_f} = \frac{A_h \cdot H_b + H_s}{A_v \cdot V_b + V_s} = \frac{H_b}{V_s} \cdot \frac{[A_h + H_s]}{[A_v + V_s]}$$

For the ground motion containing high amount of Rayleigh energy, the second term of equation 4 ($H_s/V_s$) becomes dominant that $QTS \approx \frac{H_s}{V_s}$. Many observations show that the lowest frequency of $H_s/V_s$ is nearly equal to the lowest fundamental frequency of $A_h$ [6]. It means that QTS is mostly influenced by the multiple reflection of SH despite the influence degree of Rayleigh wave.

Figure 1. The geological structure of sedimentary basin (from Nakamura)
3. Data acquisition and processing

The acquisition of microtremor is located at the area of Institut Teknologi Sumatera (Itera), covering approximately 1.5 x 1.5 km. Originally, the measurement points was designed to be gridded with space of 250 meters between points. Unfortunately, some points were located too close with the road, that the rate of transient noise from human activities were too high. After eliminating some points with low signal to noise ratio data, we processed 11 points of measurement (see Figure 2) to obtain the estimation of fundamental frequency ($F_0$) and the amplification factor ($A_0$) for area of Itera.

![Figure 2. The location of microtremor survey in ITERA, marked by the red points.](image)

The instrument used to record the microtremor signal was a 3-channels short period seismometer LE-3Dlite MKIII coupled by Taurus signal digitizer. The frequency response of the seismometer is ranging from 1Hz to 100 Hz. We performed microtremor signal recording at each point with the sampling rate 100 Hz and the duration length ranging from 45 to 60 minutes. The recording duration has already covered the minimum data length needed if the minimum $F_0$ suspected in the area reach 0.2Hz [1]. For the measurement taken on the hard ground surface, the sensor can be set directly to the ground, otherwise the artificial coupling from a flat stone plate is needed.

The microtremor data was processed using GEOPSY, an open source software for geophysical research and application. To minimize the transient noise contained in the data, Butterworth band-pass filter
ranging from 1 to 10 Hz is applied. The window length selected to calculate horizontal to vertical spectral ratio is 25 seconds. This has fulfilled the criteria that \( F_0 > 10 / \text{window length} \). The horizontal and vertical spectra is calculated by performing Fast Fourier Transform for each individual window, the spectra is smoothed by using Konno - Ohmachi algorithm with smoothing constant of 40 \(^8\). The average of H/V spectral ratio and its standard deviation then are estimated to obtain the dominant frequency of which the ground layer would resonate.

The result of H/V spectral ratio for eleven points of measurement is displayed in Figure 3. Eight from eleven points exhibit two peaks of natural frequency. Those two peaks may be associated with shallow soft deposit, thick rather stiff sediment, and very hard underlying bedrock.

![Figure 3. Example of horizontal to vertical spectral ratio measured in point 6 (a) and point 3(b) showing two peaks as \( F_0 \) around 1 Hz and \( F_1 \) around 4 to 8 Hz.](image)

4. Result and Discussion

The estimation of fundamental frequency \( F_0 \) in ITERA yields a tendency of homogeneous lateral variation with two peaks of frequency, \( F_0 \) and \( F_1 \) (see Figure 4). Both natural frequencies do not have any industrial signal source during the recording. In this case, there is possibility of two large impedance contrasts at shallow and large depth at two different scales. The variation of the estimated \( F_0 \) is ranging from 0.7 to 1.3 Hz (see Figure 4.a), while the estimated \( F_1 \) is ranging from 3.8 to 8.7 Hz (see Figure 4.b). The south-west area of ITERA tends to have slightly lower \( F_0 \) and \( F_1 \) compared to the eastern area. Based on geological data, the rock structure in ITERA consists of layered of tuff. This pyroclastic rock layer can vary from soft layer to more compact one. In this case the two different natural frequencies may be associated with the uppermost shallow soft tuff layer overlying on the much thicker and stiff tuff rock, compacted under very hard bedrock.

The map of natural frequency (\( F_0 \)) distribution shows that the western area of Itera tends to be slightly more vulnerable than the eastern area. The distribution of \( F_1 \) shows that the central area to the east is more stable compared to the south-west area. Higher natural frequency can be associated to more compact rock, while lower natural frequency is associated with soft sedimentary rock.
The amplification factor $A_0$ distribution ranging from 2.5 to 9 is mapped in Figure 5. The map shows that the central area of Itera has lower amplification factor than the north and south area. Meanwhile some research claimed that the amplification factor obtained by this method is valid [9], some claimed that the amplification factor $A_0$ underestimates the real amplification measured from earthquake strong ground motion data [10]. In this case the $A_0$ obtained in this research needs to be confirmed with the observation of real earthquake data, but this result still can be considered as the lower boundary of the real amplification factor.
Figure 4 a) The natural frequency, $F_0$, distribution ranging from 0.7 to 1.3 Hz, (b) The natural frequency $F_1$ distribution ranging from 3.8 to 8.7 Hz
5. Conclusion

The conclusion of this research are:

1. The HVSR method applied to ITERA yields two predominant frequencies, where $F_0$ is ranging from 0.7 to 1.3 Hz and $F_1$ is ranging from 3.8 to 8.7 Hz. These predominant frequencies are associated with the uppermost shallow soft tuft layer overlying much thicker and more stiffer tuff rock layer.

2. Based on the natural frequencies distribution, the west-south area of Itera may be slightly more vulnerable than the north and east area.

3. The amplification factor mapped shows that the central area has lower amplification. However, this result is only can be considered as the lower bound of the real amplification as it still need to be confirmed with the earthquake strong ground motion data.
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