Identification of Non-Uniform Ground Comparing Responses Function of Incident SH Wave by DWM to Resonance Frequency by HVSR

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Abstract. In this paper, we simulated frequency responses of subsurface due to incident SH wave by using discrete wave number method (DWM: Aki-Larner Method). It is useful in constructing the models of the non-uniform subsurface. We estimated subsurface profile based on the resonance frequency of HVSR method comparing with frequency responses obtained from SH waves incident by DWM. The only information from HVSR is the resonance-frequency of the ground. Although what obtained from the numerical analysis by DWM is a response function, it coincides with the response of the surface ground if the input motion is a white noise and the ground behaviour is a liner. In this case, the peak of response function can be considered to be a resonance frequency of the ground. Therefore, we here compared the peak frequencies of HVSR curve and response functions. To estimate the resonance frequency of ground by HVSR, the single observations of microtremor at 161 sites were carried out by using the three-component accelerometer with a data logger, GPL-6A3P, in the study area of Ende Regency that is one of five regencies in East Nusa Tenggara Province on the island of Flores, Indonesia. The results show that site response in Ende area varies the resonance frequencies span 0.7-1.4 Hz. For DWM, we assume simple two layered media with irregular boundary aimed at making a simple ground profile of the study area. The two-layered model is composed of a ‘soft basin’ on engineering bedrock. We varied the depth and the shear wave velocity of the basin and calculated response functions by using DWM. Then we selected the best fit parameters by comparing the resonance frequency of H/V result. Finally, we proposed a possible non-uniform ground model in the study area.

1. Introduction

Many earthquakes occurred in Ende Regency in the past that is one of five regencies on the island of Flores at East Nusa Tenggara Province in Indonesia. Moreover, Flores Island is as a segment of the Volcanic Inner Banda Arc and has several active volcanoes. The region with respect to the earthquakes must also be considered a high seismic activity area. That’s why we chose the study area as a site of interest, and highly susceptible of seismic hazard zone. Figure 1 shows the study area.
Detailed subsurface explorations of such ground provide key factors for the evaluation of the seismic intensity at each site. In this study, we estimated subsurface profile based on the resonance frequency of Horizontal to Vertical Spectrum Ratio method [3] comparing frequency responses obtained from SH waves incident by discrete wave number method (DWM: Aki-Larner Method) [3].

2. Estimation of Resonance Frequency (f)
Single observations of microtremor at 161 sites with an interval of about 250 m in the study area were carried out by using the three-component accelerometer with a data logger, GPL-6A3P as shown in Figure 2. This instrument is most suitable for detecting earthquake motions, ground vibration, and vibration characteristics (waveform) of buildings. The main object of this research is to perform the ground motion from especially the seismic microzonation.

Figure 1. Location of the study area

Figure 2. Location map of microtremor single station sites in Ende area
Microtremors, ground vibration, appear on the ground surface. Microtremor data analysis can be done using the method of Horizontal to Vertical Spectrum Ratio (HVSR). By looking at the peak frequency of the H/V spectral ratio, resonance frequency of ground can be estimated by [3]. Equation (1) becomes the basis for calculating the ratio of the horizontal component of the spectrum of the vertical component as expressed below.

\[
\frac{H}{V} = \frac{\sqrt{(S_{E-W})^2 + (S_{E-W})^2}}{S_{vertical}}
\]  

(1)

Where, \(H_S\) = Spectrum component horizontal layers of sediment  
\(V_S\) = Spectrum component vertical layers of sediment  
\(S_{N-S}\) = Fourier amplitude of the NS  
\(S_{E-W}\) = Fourier amplitude of the EW  
\(S_{vertical}\) = Fourier amplitude of the Vertical

The result of the analysis of the data using HVSR is resonance frequency \(f_0\) and the peak of the spectrum \(A_g\) of the H / V spectral peak that are the parameters from the reflection of dynamic characteristics of the soil layer as shown in Figure 3.

![HV Spectra](image)

**Figure 3.** An example of the spectrum of H / V results analysis

Resonance frequency \(f_0\) values of the Horizontal to Vertical Spectrum Ratio (HVSR) in this study range between 0.7 and 1.4 Hz. Figure4 shows the distribution of resonance frequency estimated each measurement site. In the Figure 4 presents large \(f_0\) value on northern and southern part overall, and small \(f_0\) value on the middle part of the area having younger deposits, we could estimate that the thickness of the plane in the middle part was thicker than on the northern and southern part.
Figure 4. Resonance Frequency Map of Ende area

3. Identification of Simple Ground model

There is no information to estimate the ground profile by array observation or other ground exploration method in the study area. So, we here identify the ground model by using simple method [3]. In this article, we adopted discrete wavenumber Method. The method expresses the ground displacement as an infinity integral of wave number. If the irregularity of the interface is assumed to be periodic, the infinity summation of wave numbers replaced the place of the infinity integral. By truncating the infinity number and introducing continuity condition of displacement and stress at the interface, it determined the unknown coefficient of the up-going and down-going wave.

Now we consider the problem for SH-wave input to two layered media. The displacement of the first (upper) and second (basement) layer as expressed below.

\[
\begin{align*}
  u_1(x, z) &= \int_{-\infty}^{\infty} \{ A_1(k) \exp(iv_1z) + B_1(k) \exp(-iv_1z) \exp(ikx)dk \\
  u_2(x, z) &= \exp \{ i(k_0x - v_0z) \} + \int_{-\infty}^{\infty} A_2(k) \exp \{ i(kx + v_zz) \} dk
\end{align*}
\]

in which \( k \) and \( v \) are wave number for \( x \)- and \( z \)-direction, respectively, and \( A_1, B_1 \) and \( A_2 \) are unknown coefficients that should be solved.

The only information obtained from HVSR is a resonance frequency. Although what obtained from the numerical analysis by DWM is a response function, the response function coincides with the response of the surface ground if the input motion is a white noise and the ground behavior is a liner. In this case, the peak of response function can be considered to be a resonance frequency of the ground. Therefore, we here compared the peak frequencies of HVSR curve and response functions.

We, first, investigated the effects of incident angles on the response of the ground because the response amplitude is affected strongly by the incident angle of the wave. Figure5 shows frequency response curves for SH wave incident angles of 0°, 30°, 45°and 60°.
Figure 5. Magnification factors of some frequency for different incident wave angles ($\theta=0^\circ$, $30^\circ$, $45^\circ$ and $60^\circ$) obtained by the discrete wave number method

For vertical incidence ($\theta = 0^\circ$) and almost vertical incidence ($\theta = 30^\circ$), the flat layer approximation made in calculations of the response amplitude is valid for certain frequency ranges. However, for larger incident angles ($\theta = 45^\circ$ and $60^\circ$) the ground irregularity must be taken into account in evaluations of the seismic response of the ground; the simple multi-layered ground model gives very different and meaningless results as shown in Figure 5. When the incident angles are $0^\circ$ and $30^\circ$, the overall trend of the transfer functions have peaks coincide. Sharp fluctuations in the transfer function, however, take place at higher incident angles. This indicates that the incident angle is not a parameter that needs to be identified when the transfer function is used as an observation value. We use the value of the incident angle ($\theta$) is $0^\circ$ because we do not know exactly the direction of the source.

In this study, we considered many profiles depend on topography in the study area and frequency map from H/V analysis as shown in Figure 6. We assumed a simple two-layered media (basin and bedrock) as in Figure 7. The ground structure of the section is roughly divided two layers; alluvial soil for the basin with an irregular interface and engineering bed rock. We fixed the shear wave velocity of the engineering bedrock as 400m/s. We changed randomly the value of the Shear wave velocity of the basin ($V_s$) between 100 m/s ~ 200m/s, the depth (D) between 50m ~ 500m and the length of the basin bottom (B) between 1km ~ 3km depend on each profile. Then we selected the best fit parameters comparing to resonance frequencies from H/V on each observation site. In Figure 8 showed an example of the comparison between the H/V ratios curves and response functions obtained results from SH wave input at an observation site.
Figure 6. Four profiles map in Ende area.

Figure 7. Schematic simple ground model for two layers media with Observation Points.

Figure 8. A comparisons between the H/V ratios curves and response functions obtained results from SH wave input at an observation site.
The results compared are listed in Table 1.1 and 1.2 for profile lines. This is the result from the best fit parameters. Figure 9 shows the ground models identified from each profile. Table 1.3 shows the shear wave velocity and depth of the basin \( V_1 \) for each profile.

Table 1.1 Comparison the value of Frequency from SH by DWM method and HVSR for profile (1&2)

| Obs. site | 18 | 17 | 15 | 7 | 10 | 8 | 80 | 140 | 48 | 139 | 86 | 83 |
|-----------|----|----|----|---|----|---|----|----|----|----|----|----|
| HVSR      | 1.02 | 0.82 | 0.73 | 0.82 | 0.92 | 1.22 | 1.36 | 2.34 | 0.78 | 0.78 | 0.87 | 1.80 |
| SH        | 1.18 | 0.87 | 0.71 | 0.79 | 0.87 | 1.18 | 2.60 | 2.36 | 0.79 | 0.79 | 1.11 | 1.34 |

Table 1.2 Comparison the value of Frequency from SH by DWM method and HVSR for profile (3&4)

| Obs. site | 141 | 68 | 90 | 132 | 143 | 51 | 95 | 116 |
|-----------|-----|----|----|-----|-----|----|----|-----|
| HVSR      | 1.02 | 0.82 | 0.73 | 0.82 | 0.92 | 1.22 | 1.36 | 2.34 |
| SH        | 1.18 | 0.87 | 0.71 | 0.79 | 0.87 | 1.18 | 2.60 | 2.36 |

Table 1.3 Shear wave velocity and depth of soil layer from SH by DWM method for each profile

| Profile | 1   | 2   | 3   | 4   |
|---------|-----|-----|-----|-----|
| Shear wave velocity by SH (m/s) | 150 | 169 | 149 | 168 |
| Depth (m) | 50  | 49  | 55  | 65  |

Figure 9. Identified ground models from SH obtained by DWM method.

4. Conclusion

In this paper, we conducted microtremor observations in Ende area, Indonesia, and numerical calculation to determine the ground profile. From the microtremor observation, we could find that the range of resonance frequency in Ende area is between 0.7 to 1.4 Hz. As the target area was between the mountains of its north and south, we could estimate that the sedimentary basin formed the plane in the middle part. Two-layered basin model was assumed. By comparing with the results of HVSR and DWM, we could propose the ground profile of a line. However, the actual ground would be more complicated.

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