Local site effect of soil slope based on microtremor measurement in Samigaluh, Kulon Progo Yogyakarta

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Abstract. This paper investigated soil slope-local site effect of earthquake inducing landslide by using microtremor Horizontal to Vertical Spectral Ratio (HVSR) method. Microtremor measurements of 15 sites which were recorded for 45 minutes at each site were carried out in Ngargosari village, Samigaluh, Kulon Progo-Indonesia. Microtremor analysis using HVSR method was performed using Geopsy software. HVSR method resulted in predominant frequency values that ranges between 2,77 to 13,82 Hz and amplification factors varied from 0,46 to 5,70. The predominant frequency is associated with the depth of bedrock and the amplification factor reflects the geological condition of soil (sedimentary layer). The soil vulnerability index (Kg) varied from 0,08 to 5,77 and the higher value (Kg>3,4) in the south of the research area was identified as the weak zone of earthquake inducing landslide.

1. Introduction

The local site effect is a response to local geological conditions (the dynamic characteristic of surface sediment layers and rocks beneath) if there was an earthquake [1]. It can lead amplification of the ground motion during the earthquake [2]. The previous research has suggested that the local site effect became one of the determinants of the destruction level of a region due to an earthquake [3][4]. In addition to cause destruction to buildings, earthquakes which occurred on the slopes can also cause the landslide [5][6]. Earthquakes can induce soil/rocks movement which changes the slope condition susceptible to move into critical condition then it finally moves [7].

This research reviewed the slope local site effects in Ngargosari village, Samigaluh, Kulonprogo. It is a part of D.I Yogyakarta located in the southern of Java Island and close to encounter between the tectonic plate of Eurasia and Hindia-Australia which had high seismic activities. In the peak ground acceleration (PGA) of the bedrock map [8], the research area had PGA value between 0,2-0,3g. The assesment of disaster mitigation (earthquake, landslide, tsunami etc) and city development plan can use geophysical and geological survey to achive the subsurface information of the area [9]. In this research, we used microtremor measurement as geophysical survey to determined the local site effects. The microtremor measurements was analyzed by using Horizontal to Vertical Spectral Ratio (HVSR) method [10] in order to obtain predominant frequencies, amplification and seismic vulnerability index value which described the slope local site effect and the potential of landslides. HVSR method is
efficient method to determine the contact between the stable and unstable layer (bedrock) which become the slip field of a landslide [11].

2. Geological Setting of Research Area
The research took place in Ngargosari village, Samigalih, Kulon Progo district, Yogyakarta (Figure 1). It was downhill area in the east of Nglinggo village and part of Menoreh Mountains. Based on the geological map of Yogyakarta [12], the research area is a part of Kebobutak formation intruded by andesite rocks. Kebobutak formation is composed by andesitic breccia, tuff, lapilli, agglomerate, and the insertion of andesitic lava flows.

At the outcrops that were located around the measurement, it was seen that the surface layers were the soil weathering effects with the insertion of weathering andesitic breccia (Figure 2 and Figure 3).

![Figure 1. The location of research area.](image1)

![Figure 2. The outcrops located around research.](image2)

![Figure 3. Weathering stones.](image3)
3. Microtremor Measurements

The micrometer measurement of 3 components (vertical, North-South, and West-East) took place at the slopes of the hill about 15 points with 45 minutes of each point and 100 Hz for sampling rate. The measurements were executed in a quiet condition by avoiding the noise of human activities and other disturbances.

The results of micrometer measurement were processed based on the HVSR method using Geopsy software by following the criteria of Sesame Project [13]. The data of each measured component was filtered by using a bandpass filter at the frequency of 1-20 Hz and hereafter a windowing process was done with window length about 10 s. The data of each window was transformed to frequency domain (spectrum) using Fast Fourier Transform method and the curve of transformation was smoothed by a smoothing process using Konno-Omachi method [14] with a constant value b=20. The spectrum results of each window in the vertical/V and horizontal components (North-South/NS and West-East/WE) were compared to the equation 1 [15].

\[ HVSR = \frac{\sqrt{US + BT}}{V} \]  

(1)

The result of the HVSR curve used was the mean value of all windows that described the predominant frequency and amplification of surface sediment layers.

4. Results and Discussion

4.1. Predominant Frequency \( (f_0) \)

Figure 4 shows the predominant frequency value of the research area ranged between 2.77 – 13.82 Hz. The predominant frequency value associated with the topographic conditions [16] and the thickness of sediment layers \( (H) \) could be estimated based on the equation 2 [17].

\[ H = \frac{V}{4f_0} \]  

(2)

where \( V \) is the velocity of the secondary wave in sedimentary layer/soil. So, the lower predominant frequency values were associated with the deeper bedrock layers.
4.2. Amplification
In Figure 5, the value of research area amplification ranged between 0.46 - 5.70. Figure 6 shows that there was no correlation between predominant frequency values to amplification so the values of amplification were not affected by the sediment thickness but they were affected by other factors. The factors that influence amplification values according to some previous researches include the impedance contrast between sediment and bedrock layers [15], the type of sedimentary layers such as shear strain, damping ratio, density[18], the water saturation of sedimentary layers [19], class of soil types [20], and quality factor of wave propagation [21].

Figure 4. Predominant frequency values of research area.
4.3. Seismic Vulnerability Index ($K_g$)

Seismic Vulnerability Index ($K_g$) of an area describes the level of soil damage due to local site effect [22]. Furthermore, the value of $K_g$ also corresponds with the level of building destruction when the earthquake came through [23]. In Figure 7, $K_g$ value of the research area was about 0.08-5.77.

The seismic vulnerability index could be correlated with the ground shear strain ($\gamma$) values describing the condition of soil dynamics when the earthquake came through [24]. The sediment layers would be inelastic and experiencing the surface deformation in the form of soil cracks which declined at $\gamma = 1000 \times 10^{-6}$. The sediment layers were experiencing the massive deformation of landslides and liquefactions if $\gamma = 10.000 \times 10^{-6}$ [3]. The calculation of the ground shear strain used equation 3 [22].

$$\gamma = e \frac{A^2}{f_0} \frac{\alpha}{\pi^2 v_b}$$

(3)

With the assumption that PGA of bedrock ($\alpha$) was maximum with the value of 0.3 g [8], shear wave velocity in bedrock layer ($v_b$) = 600 m/s and the efficiency of soil dynamic force ($e$) was 60% [22]. So, the value of $\gamma = 1000 \times 10^{-6}$ was equal to $K_g > 3.4$ and $\gamma = 10.000 \times 10^{-6}$ was equal to $K_g > 34$.

The measurement point with $K_g > 3.4$ was in the south of the research area. It was at M3 and M8 points. So, it could be deformed to be soil cracks and became weak zone of the landslide induced by the earthquake.
5. Microtremor Measurements
The predominant frequencies in the research area were varied between 2.77 – 13.82 Hz which correspond to the thickness of sedimentary layers. The value of amplification was between 0.46 – 5.70. It did not depend on the thickness of sediment but it was more affected by the geological condition of sedimentary layers and bedrock. The research area with the value of $Kg>3.4$ was a weak zone of the landslide induced by an earthquake.

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