Microseismic research using coherence and cross-correlation in Depok, Sleman, Yogyakarta

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Abstract. Yogyakarta area is one of earthquake-prone area in Indonesia. It is include in the Indo-Australian plate subduction zone under the Eurasian plate. It also has an active fault, namely Opak fault that located in Bantul Regency. Microseismic method is one way that can be used to analyze soil vulnerability of earthquakes. The Microseismic method is a geophysical method that utilizes natural vibrations as its source. The data of the Microseismic Method is processed using HVSR Method. It is used to compare horizontal to vertical spectra ratio. The results of HVSR shows the value of the dominant frequency \( f_0 \), amplification \( A_0 \) and the Soil Vulnerability Index \( K_g \).

The results of this research that especially located in Depok District, Sleman Regency has the dominant frequency value that range from 0.65 to 1.35 Hz, amplification value between 2.6 and 5.6 and soil susceptibility value is 4-52 s²/cm. The data obtained from the southern part of the research area, it shows that it has dominant frequency and high amplification values. To reassure the data, coherence graphs, phase velocity graphs and cross correlation maps were made between amplification maps with dominant frequencies, dominant frequency maps with topography, amplification maps with topography and maps of soil vulnerability index with topography. Coherence and correlation cross graphs show a small link to the south of the research area.

Keywords: Amplification, Frequency Dominant, Soil Vulnerability.

1. Introduction
Yogyakarta area is part of the earthquake zone in the Indo-Australian plate subduction zone with the Eurasian plate. Based on seismic conditions, the southern zone of Java Island has a fairly high earthquake rate [1]. Yogyakarta besides being prone to earthquakes due to the collision of both plates, this area is also prone to earthquakes due to local fault activities on land [2]. The fault is formed due to pressure from the Indo-Australian plate on the mainland of Java.

Microtremor is an ambient weak vibration of the ground caused by natural or artificial disturbances such as wind, sea waves, traffic, and industrial machinery. The amplitude level of the microtremor is typically less than several microns. [3]. The method used to identify the microtremor seismic data is often called the microseismic method. The microseismic method measures vibration with a small magnitude (<3 SR). The source of vibration obtained from the nature. One of the data processing of
microseismic methods is the Horizontal to Vertical Spectral Ratio (HVSR). The processing of the HVSR method shows the predominant spectrum \( f_0 \) and amplification factor \( A_0 \) which describes the dynamic characteristics of the soil [4]. The dominant frequency value and amplification can be used to calculate the value of soil vulnerability \( K_g \).

This research aimed to get the map of \( A_0, f_0, K_g \). Each map is sliced for further coherence and cross correlation. Coherence graphs is used to determine the integration between the two parameters and cross-correlation maps which can be used to determine the relationship between the two parameters, so that from the graph can be known to areas prone to earthquakes. Coherence and low cross-correlation values can illustrate that the area is an area prone to earthquakes.

2. Regional Geology

The Yogyakarta area was formed from the lifting of the Southern Mountains and Kulon Progo Mountains in the early Pleistocene Period (0.01-0.7 million years). After the lifting of the Southern Mountains, lakes formed along the foot of the mountains to Gantiwarno and Baturetno. Merapi Volcano appeared 42,000 years ago, but the age of K / Ar Andesite lava on Mount Bibi determines the activity of Mount Merapi which has been going on since 0.67 million years ago [5].

The lifting of the Southern Mountains in the Early Pleistocene formed the Yogyakarta Basin. Within the Yogyakarta Basin, volcanic activity developed (Mount Merapi). Higher zone in the south and the appearance of the Mount Merapi dome on the north formed a flat valley. The southern part of the valley borders the Southern Mountains and the western part of the valley borders the Kulon Progo Mountains. The location which was suspected that formed a flat valley exposes a black clay deposits. The deposit of black clay is the contact limit between the bedrock and sediment of Merapi Volcano. The thickness of the volcanic deposits of Merapi Volcano can reach 100 meters. Based on data carbon dating 14C in black clay deposits located in Progo (Pity), the age of the flat valley ± 470 years, while in the River Opak (Watuadeg) 6,210 years old. Black clay deposits on the Opak River interspersed with the sediment of Mount Merapi and the data can be interpreted as the beginning of the influence of the deposition of Mount Merapi in this region. On the Winongo River (Kalibayem), black clay deposits are scattered around the 310-year-old lava.

3. Theory

3.1. Natural Frequency \( (f_0) \)

The natural frequency value of HVSR processing describe the natural frequency in the area. Low natural frequency characteristics with long period earthquake wave vibrations [2] describe the weak zone and it is a dangerous indication because it can cause damage to buildings if there is any force to the ground like earthquake. The limitation of frequency observation for microtremor is generally between 0.5-20 Hz and for small frequency, microtremor can reach 0.2 Hz. The natural frequency value of an area is affected by the thickness of the weathered layer and the average velocity of the subsurface [6].

The dominant frequency value of the soil can indicate the type and characteristics of the rock. The dominant dominant frequency value is in hard rock while the dominant dominant frequency value is in soft rock [7].

3.2. Amplification Factor

Amplification of a wave can occur when an object that has its own frequency is disturbed by another wave with the same frequency. Earthquake wave amplification can occur when waves propagate to the surface of the ground as long as the natural frequency of the soil has the same or almost the same value as the earthquake frequency.

According [8] there are 4 causes of amplification of a region, namely:

a. Weathered layer that is too thick above the hard layer
b. \( f_0 \) (natural ground frequency) is low
c. \( f_0 \) earthquake with local geology is the same or almost the same
d. Earthquake waves stuck in weathered layers for a long time.

The earthquake amplification factor is the ratio of the maximum velocity of an earthquake on the ground surface to bedrock. The amplification factor value somewhere can be seen from the peak height of the HVSR amplitude spectrum measured at the place [4].

3.3. Soil Vulnerability

According to [4] Soil Vulnerability Index ($K_g$) identifies the level of vulnerability of a soil layer deformed by an earthquake with the following equation:

$$K_g = \frac{Am^2}{f}$$ (1)

With $Am$ and $f$ is the amplitude (amplification factor) and HVSR frequency. High $K_g$ values are generally found in soils with soft sedimentary lithology. This high value illustrates that the area is vulnerable to earthquakes and if an earthquake occurs, it can experience a strong shock and vice versa. Classification of soil vulnerability index According to [2] are:

a. $K_g < 10$ has a low soil susceptibility index
b. $10 < K_g < 20$ is in the medium category
c. $K_g > 20$ is classified in the danger zone.

3.4. Coherence

Coherence is the link between one part and another, so that a data has a unified meaning. Coherence value cannot be negative because coherence is multiplied by the magnitude value. The highest value of coherence is 1 and the lowest value of coherence is -1. Coherence value 1 illustrates that the relationship between two parameters is very strong, while the value of coherence 0 illustrates that the relationship between two parameters is lacking [9]. The coherence formula is as follows

$$Coh = \frac{Cx \ast Cy}{\sqrt{C_x^2 \ast C_y^2}}$$ (2)

With $Coh$ is coherence, $Cx \ast$ is data 1 (complex conjugate), $Cx$ is data 2 and $Cy$ is data 2.

3.5. Cross Correlation

The purpose of cross correlation is to measure the similarity / conformity (conformity) of two functions. Cross correlation maps produced in this research aimed to ensure the results obtained from the results of coherence processing. The value of cross correlation can produce negative values. The maximum value of cross correlation is 1 and the minimum value of cross correlation is -1. The value of cross correlation 1 illustrates that the relationship between two parameters is very strong, while the value of cross correlation 0 illustrates that the relationship between two parameters is absence.

4. Method

The first thing to be done after obtaining microseismic data in the research field was processing it with Geopsy Software (http://www.geopsy.org/index.html) and processed using Horizontal to Vertical Spectral Ratio (HVSR) analysis to get the values $A_0$ and $f_0$. After the values of $A_0$ and $f_0$ are obtained, the data was transferred to calculate the value of soil vulnerability ($K_g$). Eventually, the coherence graph and cross correlation map were made.
5. Result

5.1. Dominant Frequency

Figure 1 is the dominant frequency map in the research area. From the obtained data of field measuring, the dominant frequency value of the research area has the range from 0.65 to 1.35 Hz. High frequency values are in the southern part of the research area which are described in red. The area is estimated to be an area with high population density. It can be estimated that the area has geological conditions with dense sediments. Low frequency values are in the west and southeast of the research area which are depicted in purple to blue. Areas with low frequency value can be described that the research area has a thick layer of sediment.

Figure 1. Dominant Frequency map.

5.2. Amplification

Figure 2 is the amplification map of the research area. The amplification values obtained from the HVSR process of field data ranged from 2.6 - 5.6. High amplification values in the research area are described in yellow to red which tend to be in south of the research area. This high amplification value can show that the research area has less compacted sediment layer and soft sediment texture. The low amplification value is depicted in blue to purple which is in to the north of the research area. By the low amplification values, it can be estimated that the area has compact and hard sediment thickness.

Figure 2. The amplification map
5.3. **Soil Vulnerability**

Figure 3 is the map of soil vulnerability obtained from the field. According to [2], the value of vulnerability that is classified as high has the value of > 20 s²/cm, the value of the moderate vulnerability is between 10-20 s²/cm and the value of low vulnerability has a value of <10 s²/cm. From the results of HVSR calculation of the field data, the vulnerability value of the soil in the research area has the range from 4 to 52 s²/cm. Almost all research areas have low vulnerability value to moderate according to the classification by [2]. The high vulnerability value of the soil in Figure 5.6 is illustrated in yellow to red and bounded by a black line. It can be interpreted that the value of high vulnerability is an area prone to earthquakes and has a large value of building damage when a shock happens, while the low vulnerability value is illustrated in purple to blue. It can be indicated that the area is in an earthquake safe zone and has small building damage in the event of an earthquake disaster.

![Figure 3. Soil vulnerability map](image)

5.4. **Coherence and Cross Correlation**

**$A_0$ and $f_0$ Coherence and Cross Correlation**

From Figure 4 a), it can be seen that the coherence graph in the North-South slice has a low value in the south. The coherence chart in the West-East slice has a low value in the east. This low coherence value illustrates that the research area is an area that is prone to shocks. In Figure 4 b), it can be illustrated that the high cross correlation value is in the North, while the low cross correlation value is in the South. The value of cross correlation is high at the value of 0.6, this indicates that the cross correlation between the amplification value and the dominant frequency is not very good, but the area is safe to be shaken and the cross correlation value is low at the value -0.6, this indicates that the north area is a shock-prone area.
Figure 4. a). Coherence b). Cross Correlation between $A_0$ and $f_0$

$f_0$ and Topography Coherence and Cross Correlations

In Figure 5 a.), it can be illustrated that the high cross correlation value is in the North, while the low cross correlation value is in the South. The value of cross correlation is high at the value of 0.6, this indicates that the cross correlation between the amplification value and the dominant frequency is not very good, but the area is safe to be shaken and the cross correlation value is low at the value of -0.6, this indicates that the north is a shock-prone area. From Figure 5 b.), it can be seen that the coherence graph in the North-South slice has a low value in the south. A coherence chart in the West-East slicing has a low value next to it. This low coherence value illustrates that the research area is an area that is prone to shocks.

Figure 5. a). Coherence b). Cross Correlation of $f_0$ and Topography

Cross-correlation maps between North-South slicing (a) with East-West slicing (b) have similar patterns. On the map, it can be illustrated that the high cross-correlation value is in the middle of the research area, while the low cross-correlation value is in the West and East of the research area. The high cross correlation value is 0.4, this indicates that the cross correlation between the amplification value and the dominant frequency is not good, but the area is safe to be shaken and the cross correlation value is low at -0.4, this indicates that is shock-prone area.

$A_0$ and Topography Coherence and Cross Correlations

From Figure 6 a.), it can be seen that the coherence graph in the North-South slice has a low value in the south. The coherence chart in the West-East slice has a low value in the east. This low coherence value illustrates that the research area is an area that is prone to shocks.
Figure 6. a). Coherence b). Cross Correlation between $A_0$ and Topography

Figure 6. b). Cross-correlation maps between North-South slicing (a) with East-West slicing (b) have similar patterns. On the map, it can be illustrated that the high cross-correlation value is in the North, while the low cross-correlation value is in the South. The value of cross correlation is high at the value of 0.6, this indicates that the cross correlation between the amplification value and the dominant frequency is not very good, but the area is safe to be shaken and the cross correlation value is low at the value of 0.6, this indicates that the north is a shock-prone area.

Kg and Topography Coherence and Cross Correlations
From Figure 7 a)., it can be seen that the coherence graph in the North-South slice has a low value in the south. The coherence chart in the West-East slice has a low value in the east. This low coherence value illustrates that the research area is a shock-prone area.

Figure 7. a). Coherence b). Cross Correlation of Kg and Topography

Figure 7. b). Cross-correlation maps between North-South slicing (a) with East-West slicing (b) have similar patterns. On the map, it can be illustrated that the high cross-correlation value is in the North, while the low cross-correlation value is in the South. The value of cross correlation is high at the value of 0.6, this indicates that the cross correlation between the amplification value and the dominant frequency is not so good, but the area is safe to be shaken and the cross correlation value is low at the value of -0.6, this indicates that the north is a shock-prone area.

6. Conclusion
Based on the results of research conducted in Depok District, Sleman Regency, Yogyakarta, the following conclusions were obtained:

a. The obtained frequency value obtained has the range from 0.65 to 1.35 Hz. The research area is dominated by small dominant frequency value. Areas with small frequency are the areas...
with high sediment thickness, while areas with greater frequency are the areas with thinner sediments.

b. The value of amplification obtained in the research area has the range of 2.6-5.6. The higher amplification value indicates that the research area has a large signal reinforcement.

c. The vulnerability value of the soil obtained in the research area ranged from 4 to 52 s²/cm. Vulnerability value of the soil is high, especially around the location points of 22 and 23 because the research area has less compact but thin sediments.

d. Graph of coherence between amplification and dominant frequency, dominant frequency and topography, amplification and topography, and soil susceptibility index and topography shows coherent values except in the southern part of the North-South and East slicing in the East-West slice. Cross-correlation map of N-S and E-W slicing between amplification and dominant frequency, dominant frequency and topography, amplification and topography, and soil susceptibility index and topography shows almost the same value. This cross-correlation map also shows comparable values with coherence charts.

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