Design Of Microtremor Monitoring Tools Using Accelerometer Sensor On Android Mobile To Determine The Natural Building Frequency In UNS Library

Rio Riantana¹, Darsono¹, Agus Triyono²
¹Physics Department of Sebelas Maret University, Indonesia
²Indonesian Agency for Meteorology, Climatology and Geophysics, Yogyakarta, Indonesia
E-mail: riariantana@yahoo.com

Abstract. Design of Microtremor monitoring tools using accelerometer sensor on android phone to determine the natural frequency of buildings in UNS Library has done. This study aims to determine the ratio of resonance between the soil and building of UNS Library. The main sensor for recording microtremor activity is Accelerometer sensor on android phone. Microtremor activity recording is done on every building’s floor of UNS Library and the surface of land outside the building. The recorded data has been sent to the server by telemetry method. The data stored on the server then displayed in the graph on the microtremor web monitoring. Microtremor data is processed with the FFT to determine the dominant frequency. From the dominant frequency, ratio of resonance of soil and building of UNS Library could be found. The value of resonance ratio is 69.35 - 94.48% in the NS component and 70.42 - 98.61% in the EW component with low resonance status on each floor of the building.

1. Introduction
Microtremor is a very small and continuous ground vibration that is sourced from various kinds of vibrations such as, traffic, wind, human activity, and others. Microtremor can also be interpreted as a continuous natural harmonic vibration of the soil, trapped in surface sediments, reflected by a fixed layer or boundary layer, caused by micro vibrations below the surface of the soil and other natural activities. Microtremor can be measured by a microtremor meter device that consisting of amplitude and period measurements. In the study of seismic techniques, lighter lithology has a higher risk when shaken waves of earthquakes, because it will make greater amplification (wave) compared with more compact rock [1].

One important factor that can be used to predict earthquake hazard in a building is the resonance measurement between the natural frequency of the building and the ground below the building [2]. If the value of the building frequency is close to the natural frequency value of the underlying material, the seismic vibration will give rise to resonance in the building which will increase the stress on the building [3]. Nowadays many technologies have been created to analyze various natural phenomena such as earthquakes. Technology in today is already very complex. Not only used as a medium of communication between humans, but also as a medium of information between humans and the natural surroundings.
Android is one of the Operating System (OS) that dominates the smartphone market. Android is open source that allows users to optimize the functions of the devices available on the smartphone [4]. In the android device generally, there is a motion sensor that is accelerometer sensor. Accelerometer sensor on android is used to determine the orientation of motion on the android smartphone. The accelerometer on the android smartphone measures the acceleration of movement with units of m/s² [5]. Sensor is very sensitive and can detect microtremor vibration. This study aims to determine the ratio of resonance between the soil and building of UNS Library using accelerometer sensor on android mobile.

2. Method

2.1. Collecting data process of natural vibration of the soil and vibration of buildings around of UNS Library Building

Data collection of land and building frequency are done by installing Android mobile phone on ground level around UNS Library and every floor of UNS Library. Android Mobile placed on mounting. Android phone was setting its level so that the axis exactly in accordance with its position. Taking data at each point is done for approximately 30 minutes to 1 hour. From the vibration data during that period, the vibration data will be convert from the time domain into the frequency domain. This conversion process used Fast Fourier Transform (FFT) method.

![Flowchart of microtremor data retrieval](image1)

Figure 1. Flowchart of microtremor data retrieval

![Configure microtremor data retrieval point](image2)

Figure 2. Configure microtremor data retrieval point
2.2. Data analysis technique

Data analysis technique is done by Fast Fourier Transform (FFT) method

\[ X(f) = \int_{-\infty}^{\infty} x(t) e^{-j2\pi ft} dt \]

\[ X(f) = \int_{-\infty}^{\infty} x(t) \cos(2\pi ft) dt - j \int_{-\infty}^{\infty} x(t) \sin(2\pi ft) dt \]

\( X(f) \) is a signal function in the frequency domain, \( x(t) \) is a signal function in the time domain, \( e^{-j2\pi ft} \) is a kernel function, and \( f \) is frequency. Equation (1) is a function used to transform signals from time domain to frequency domain.

\[ X(f)_{EW} = \int_{-\infty}^{\infty} x(t)_{EW} \cos(2\pi ft) dt - j \int_{-\infty}^{\infty} x(t)_{EW} \sin(2\pi ft) dt \]  

\[ X(f)_{NS} = \int_{-\infty}^{\infty} x(t)_{NS} \cos(2\pi ft) dt - j \int_{-\infty}^{\infty} x(t)_{NS} \sin(2\pi ft) dt \]  

\[ X(f)_{UD} = \int_{-\infty}^{\infty} x(t)_{UD} \cos(2\pi ft) dt - j \int_{-\infty}^{\infty} x(t)_{UD} \sin(2\pi ft) dt \]

\( X(f)_{EW}, X(f)_{NS}, \) and \( X(f)_{UD} \) is a signal function in the frequency domain on the EW, NS, and UD axes. Each point of vibration measurement will get the result of all three axes. From these three axes can be analyzed HVSR (Horizontal to Vertical Spectral Ratio) and FSR (Floor Spectral Ratio). The equation for HVSR is shown in (6), and the equation for FSR is shown in (7) and (8).

\[ HVSR = \frac{\sqrt{(X(f)_{EW})^2 + (X(f)_{NS})^2}}{X(f)_{UD}} \]  

\[ FSR_{EW} = \frac{x_b(f)_{EW}}{x(t)_{EW}} \]  

\[ FSR_{NS} = \frac{x_b(f)_{NS}}{x(t)_{NS}} \]

Analyzes for natural soil vibrations using HVSR (Horizontal to Vertical Spectral Ratio) analysis, than analysis on each floor of the building using FSR (Floor Spectral Ratio). The HVSR value is obtained from the comparison between the natural ground vibrational frequencies on the horizontal axis (EW and NS) with the natural ground vibrational frequencies on the vertical axis (UD). The FSR value is obtained from the comparison between the vibration frequency of the building and the frequency of the ground on the same axis. \( FSR_{EW} \) is the floor spectral frequency on the EW axis, and \( FSR_{NS} \) is the spectral frequency of the building floor on the NS axis. The data processing will be done by calculation of resonance ratio of land and building with equation (9).

\[ R = \left| \frac{f_b - f_t}{f_t} \right| \times 100\% \]  

\( R \) is the resonance ratio, \( f_b \) is the resonance of the building, and \( f_t \) is the soil resonance. Levels of resonance of building to earthquakes are classified into three, low if resonance value \( (R) > 25\% \), medium if resonance value \( (R) = (15\% - 25\%) \), and high if resonance value \( (R) < 15\% \) [6].

3. Discussion

3.1. Natural vibration data of soil and buildings in around of UNS Library Building

Microtremor data retrieval was done after 12 pm. As shown in Figure 2, the location of microtremor data collection includes the basement floor up to the 7th floor of the UNS Library Unit, and in the open space around the courtyard of UNS Library. Data collection in the building is done by placing an android phone in the center of the building. Placement on the 2nd, 3rd, 4th, 5th, 6th, and 7th floors is positioned in front of the building lift as it is the most central position. For the first-floor mobile placement location placed in front of Front Office. For the basement, floor position is placed just below the position of the first-floor placement. As for the location outside the building is placed in the south of UNS Library Units.
**Figure 3.** The 4th-floor microtremor graphic clip on the X-axis (a) the Y-axis (b) and the Z-axis (c)

**Figure 4.** The dominant frequency graph of EW (a), NS (b), and UD (c) on the 4th floor of the UNS Library
Data collection on each floor is done with duration 30 to 60 minutes. Before running the program, device android paired on the mounting and adjusted its leveling. Mounting is fixed to the floor using a double-foam tape. An example of a recording of a microtremor recording graph on the 1st floor is shown in Figure 3.

After getting data microtremor, the data will be calculated to the dominant frequency values, HVSR and FSR. In the determination of the Dominant Frequency used Fast Fourier Transform, Short-Time Fourier Transform, and vibration spectrum. These functions are already widely available in modern programming languages such as C, C #, C ++, IDL, Java, and Phyton. Determination of the dominant frequency value is done by processing the microtremor data in the Matlab R2013a from the MathWorks developer [7]

After obtained the dominant frequency, it can be known the value of HVSR and FSR. The dominant frequency data shown in Table 1. The dominant frequency graph is shown in Figure 4.

| Location     | NS (Hz) | EW (Hz) | Z (Hz) |
|--------------|---------|---------|--------|
| Basement     | 3.691   | 4.980   | 3.203  |
| 1st Floor    | 1.269   | 3.242   | 1.679  |
| 2nd Floor    | 3.262   | 2.129   | 1.641  |
| 3rd Floor    | 3.906   | 1.641   | 0.391  |
| 4th Floor    | 2.168   | 3.223   | 1.367  |
| 5th Floor    | 4.121   | 1.504   | 1.719  |
| 6th Floor    | 0.742   | 0.234   | 2.031  |
| 7th Floor    | 1.797   | 4.668   | 0.273  |
| Outside Building (Ground) | 3.945 | 4.941 | 1.855 |

Calculation of HVSR value refers to equation (6), obtained HVSR value is 3.407772. While the calculation of FSR value refers to equation (7) and (8), FSR value on each floor of UNS Library shown in Table 2.

| Location     | NS          | EW          |
|--------------|-------------|-------------|
| Basement     | 0.93561470  | 1.0079052   |
| 1st Floor    | 0.32167300  | 0.6561424   |
| 2nd Floor    | 0.82679823  | 0.4308300   |
| 3rd Floor    | 0.99011407  | 0.3320158   |
| 4th Floor    | 0.54954854  | 0.6522435   |
| 5th Floor    | 1.04463726  | 0.3043478   |
| 6th Floor    | 0.18813384  | 0.0474308   |
| 7th Floor    | 0.45548162  | 0.9446641   |

3.2. Analysis of microtremor data results

Data analysis is done by comparing the FSR value of each floor of UNS Library with HVSR value of the surrounding the soil. The results of the FSR value data in Table 2 were processed using equation (9). Levels of resonance of buildings to earthquakes are classified into three, low if resonance value (R) > 25%, medium if resonance value (R) = (15% - 25%), and high if resonance value (R) <15% [6].
Table 3. Value of Building Resonance Ratio UPT Library UNS.

| Location | R (NS) % | R (EW) % | Status (NS) | Status (EW) |
|----------|----------|----------|-------------|-------------|
| Basement | 72.54    | 70.42    | Low         | Low         |
| 1st Floor| 90.56    | 80.74    | Low         | Low         |
| 2nd Floor| 75.74    | 87.36    | Low         | Low         |
| 3rd Floor| 70.95    | 90.26    | Low         | Low         |
| 4th Floor| 83.87    | 80.86    | Low         | Low         |
| 5th Floor| 69.35    | 91.07    | Low         | Low         |
| 6th Floor| 94.48    | 98.61    | Low         | Low         |
| 7th Floor| 86.63    | 72.28    | Low         | Low         |

From the results, obtained data show that the resonance ratio of building on each floor of the building UNS Library is low. The resonance ratio value on each floor is different. The difference is due to the height of the soil surface, the combination of the air column underneath, the layout on each floor, and others. The function of space on each floor also affects the natural frequency on the floor. On the basement floor, the room is below ground level outside the UNS Library Units. In this basement room, the room is not sealed but a rather large room with several pillars. Frequency in this basement space is high compared to other spaces above. The frequency of the basement floor on the NS and EW axes almost matches the frequency of the ground whereas the frequency value on the larger z axis. On the 1st floor, the room is larger because it is used as a front office library. On the 1st floor, there is an internal server of UNS Library which is to the south of the data retrieval point. From Table 2 it’s known that the dominant frequency value on the Y-axis (NS) is greater than the X-axis (EW). This is due to the existence of the internal server UNS Library is active. On the 2nd floor is used for Administration room and meeting room. On the 3rd floor to 6th floor, half the room functioned as reading room and half again as information center, mushola and bathroom. Almost on the floor, the frequency value is almost the same except on the 6th floor which the dominant frequency value is small. On the 7th floor, the function and layout are different from the floor below. On the 7th floor is functioned as a UNS Museum.

The resonance ratio in the NS direction varied between 69.35 - 94.48%, also on the EW axis is 70.42 - 98.61% as shown in Table 3. Greater the resonance ratio is better the natural frequency at that location further away from the natural frequency of the ground. In Table 2. shows the dominant frequency values varying on each axis. In this study for the dominant frequency of buildings analyzed is the frequency on the horizontal axis of NS and EW. The orientation of vibration that significantly affects the strength of the building in the horizontal direction. The tower-like shape of the building makes it very vulnerable to collapse when subjected to vibration especially vibration with horizontal orientation. Usually, the frequency values in the direction of NS and EW close to the same or the difference is not much. But in this study, the average value of the dominant frequency in the direction of NS and EW is bold difference. This can be caused by the location of the building around the building of the UNS Library Unit. Figure 5. shows the location of UNS Library. The average value of the dominant frequency in the NS direction is greater than the EW. This is because there is an effect of vibration activity from the flanking building in the north and south, and caused by thickness profile of top soil.
4. Conclusion

The natural frequency values structure of UNS Library as shown in Table 2. From the data obtained, it shows that the resonance ratios of buildings on each floor of the UNS Library are low. The resonance ratio value on each floor is different. The difference is due to the height of the soil surface, the combination of the air column underneath, the layout on each floor, and others. The function of space on each floor also affects the natural frequency on the floor. The resonance ratio in the NS direction varied between 69.35 - 94.48%. The resonance ratio on the EW axis varies between 70.42 - 98.61%. The greater the resonance ratio the better because of the natural frequency at that location further away from the natural frequency of the ground. The average value of the dominant frequency in the NS direction is greater than the EW. This is because there is an effect of vibration activity from the flanking building in the north and south, and caused by thickness profile of the top soil.

Reference

[1] Kinai, K. 1983. Engineering Seismology. (Tokyo: University of Tokyo).
[2] Gosar, A. 2010. Geofizika, 28 2011.
[3] P. Kvasnicka, L. Matesic, K. Ivandic. 2011. Geofizika, 2011
[4] K. Sokolovaa, C. Perezb, M. 2016. DECSUP 15 12763.
[5] Riantana R. 2015. Jurnal Fisika Dan Aplikasinya. 11 114-119
[6] Aini D.N., Utama D., Bahri A.S. 2012. JURNAL TEKNIK POMITS. 1 1-5.
[7] Telgársky, Rastislav. 2013. arXiv:1306.0103v1 [cs.NA]