Microtremor Study of Site Effect for Disaster Mitigation and Geotechnical Purpose

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Abstract. Makassar city have relatively lower earthquake vulnerability compared to other regions in Indonesia, however detailed mapping related to seismic wave amplification needs to be done in the interest of geotechnical, regional planning and disaster mitigation. It is generally known that the magnitude of the damage during the occurrence of earthquakes or tremor occur periodically is influenced by the dynamic characteristics of the building as a function of seismic wave amplification. The degree of seismic wave amplification depends on several factors, including the thickness of the sediment layer, the level of compaction and the geological age factor. The purpose of this research is to investigate seismic vulnerability in Makassar by using spectral comparison through microtremor measurement. There are several of the approaches that can be done and microtremor is the easiest and cheapest method to understand these dynamic characteristics without causing damage effects. Spectra comparison technique used was popular by Nakamura, which is comparison technique of horizontal component noise spectra and the vertical component in sediment areas (H/V spectra). Results from seismic vulnerability index (SVI) distribution maps show values ranging from 0, 14 – 158, 31. In general, the eastern part of the city of Makassar near from coastal areas is more vulnerable to damage especially earthquakes or periodic earth tremor with certain dominant frequency compared with the western part of Makassar City.

1. Introduction
Almost all big cities in Indonesia have high levels of earthquake vulnerability but are not supported by detailed mapping of earthquake risk in that area. One mapping method that nowadays gains popularity because cheaper and easy to apply is a method of using microtremor surveys. Although microtremor surveys have not been widely applied in Indonesia, in some countries such as Europe and Japan have conducted these surveys and contribute significantly for disaster mitigation, geotechnical purpose, and urban planning. The city of Makassar, even though data seismicity zone issues by Ministry of Public Works [1] is relatively lower than in other areas, lay on sediment are which gives site effect on the effects of damaged buildings due to the vibrations that occur on the surface. It is also found in several cities in the world that lay on sediment are, like in Turkey, Lebanon, Kroasi and Italy [2-6]. The subsurface topography and geological conditions of an area gave significantly on the extent of damage caused by earthquakes in the area. Several studies have shown that major damage is caused by the effects of the site [7, 8].

Spectra comparison technique used is Nakamura technique, that is comparison technique of horizontal component noise spectra and the vertical component in sediment areas (H / V spectra).
This technique can also be combined with other geophysical measurement methods and geotechnics to produce unique solutions [3, 4].

The use of HVSR method is quite suitable for Makassar City, considering the geology of Makassar city area located on the sediment of alluvium and marine sedimentary rocks, so it is the right area to do the research in determining the effect of the local site (site effect). Basemen (hard rock) from Makassar based on geological map consist of Camba formation rock rocks (breccia, lava, conglomerate, and tuff) in Maros and volcanic eruptions, Lompobattang volcano (conglomerate, lava, breccia, sediment, lava, and tuff) especially volcanic lava rocks found in the area around Gowa. This technique is also suitable to use in Makassar since this area based on seismicity maps issued by USGS [9] is relatively small so it is difficult to determine the effect of local sediment (site effect) using earthquake data.

This method provides information about the characteristics of the sediment layer such as the dominant frequency and amplification factors, so that the potential damage to the city of Makassar can be known and very useful for disaster mitigation, especially due to the fault with the north-east of Makassar potential source of earthquakes which is very damaging effect on the city of Makassar.

2. Data and Methodology

2.1. Geological Setting

Makassar City's bedrock located in the area around Maros District well known as Camba formation volcanic rock consists of breccia, lava, conglomerate, and tuff. Makassar's landscape is a coastal plain found in the west and north of the main street of Makassar City-Maros District and directly adjacent to the river plains and floodplains.

River plains and floodplains are found between the two large rivers that divide the city of Makassar Jeneberang River and Tallo River. Floodplains occupy the river area and the highland found in the northern, eastern and southern parts of Makassar City which include the area of Biringkanaya and Panakukang.

Based on the geological map of Makassar City as shown in figure 1, it is generally composed of 3 rock units:

1. Alluvial sediment, these alluvial rock units dominate almost all areas of the city with an area of 11,693.83 ha. Its spread covers the area around the mainland to the coast.
2. Basal Rock, the distribution of basalt rock units is located in two districts of Tamalate sub-district with an area of 3.201 ha and in Biringkanaya District with an area of 25.027 ha.
3. Sediment comes from seas interbedded with Bawakaraeng volcanic rocks, and Camba Formation consisting of lava, breccia, tuff and conglomerate result from Gunungapi Batturappe-Cindako in the form of tuff and breccias, the distribution of tuff and breccias is located in Biringkanaya Subdistrict, Tamalate Sub-district, and Kecamatan Panakukang.
2.2. Microtremor

Okada [10] defined microtremor is the constant vibration of earth’s surface. The source of microtremor comes from the active source and passive source. Active source created by human activity (vehicles or plant machinery vibration) and passive source rise from natural phenomena (ocean waves, wind, rain, and variations in atmospheric pressure). Vibration in term of microtremors refers to not including short duration events such as earthquakes and explosions [11].

Microtremor surveys can be performed in two ways depending on seismic activity in the area [12]. The first approach is well known as the classical method which is good for high seismic activity. This method needs two or more station locations that recorded simultaneously, one station should be put in an area of hard rock (basement) that doesn’t indicate a strengthening of frequency due to a ground vibration and others should be put in soft rock (sediment) indicate the amplification of seismic wave. These two or more Station in two area will be compared to get response microtremor spectrum as a transfer function. This approach quite difficult to perform since we need an area with hard rock (basement) and also need sufficient earthquake that record in both area.

The second approach popular by Nakamura [13], he named it as H/V spectral ratio. The advantage of this method only needs one station, the procedure very simple the spectra ratio of horizontal and the vertical components recorded at the same site (H/V spectral ratio). This technique attractive since it gives ease of data collection and it can be applied to an area of low or even no seismicity. Nakamura assumes that the H/V ratio reflects the amplification of ground motion. With this method of measurement does not need to be done with the requirements of the hard rock.

Stasion site can be seen in figure 2. A measurement performed using a set of short-period seismograph-303S portable type TDL (3 components), each of which consists of a digitizer, sensors, laptops, batteries, and GPS.

Ambient noise data (microtremor) obtained from 106 measurement points are scattered in the area Makassar City, Maros District and Gowa District (figure 2). Recording the data onto each point measurements was performed for approximately 30 minutes. An example of one station of data collection can be seen in figure 2.

![Figure 2](image)

**Figure 2.** Map of research site and An example raw data measurement (Arka Station).

In processing data, the Geopsy software we used. This software contains information on recording time, the amount of data, and other supporting data. The result is a spectrum at each station will then be analyzed to obtain the HVSR peak value (A) and predominant frequency (f0).

At the time of processing using GEOPSY software, data is divided into several windows (figure 3). If the data is large enough sorting windows is automatically provided by the software. Windowing is the process to sort data onto the tremor signals and transient event (especially specific sources such as footsteps and vehicle passes). If signal quite difficult to sort automatically, event detect manually to prevent the transient event.
The next are fast Fourier transform (FFT), which involves the process of smoothing. The smoothing process is done by using Konno and Omachi algorithms [14] with a bandwidth \( b \) coefficient of 40. In this process, we also did cosine taper to minimize border effect or boundary effects due to the selection process window. The end results of the processing of data onto the form of spectral ratio \( H / V \) (figure 3). From this spectrum, we can determine the value of the dominant frequency (\( f_0 \)) and peak spectral ratio \( H / V \) (A) at the measurement site microtremors. Based on the relationship \( T = 1/f_0 \) then we will get the value of a dominant period in the measurement site [15].

2.3. HVSR Technique
This technique widely used for micro-zoning and engineering purposes proposed by Nakamura [13]. The H/V spectral ratio \( T_{H/V(\omega)} \) was obtained by dividing the average spectra of the horizontal component of sediment site \( [s_{HS}(\omega) + s_{HB}(\omega)] \) by the spectrum of the vertical component \( S_v(\omega) \) of the sediment site:

\[
T_{H/V(\omega)} = \frac{s_{HS}(\omega) + s_{HB}(\omega)/2}{S_v(\omega)}
\]  

(1)

Based on Nakamura Idea, amplitude effect of Source can be estimated by the ratio:

\[
A_S = \frac{V_S}{V_h}
\]

(2)

where amplitude spectrum of the vertical component of motion at the surface and amplitude spectrum of the vertical component of motion at the half-space defined as \( V_S \) and \( V_B \). Nakamura also estimates site effect of interest in earthquake engineering (\( S_E \)), as a ratio

\[
S_E = \frac{H_S}{H_B}
\]

(3)

where \( H_S \) and \( H_B \) are Fourier amplitude spectra of the horizontal component of motion at the surface and the base of soli layer.

Using assumption:

\[
\frac{H_S}{V_h} = 1
\]

(4)

We can calculate modified site affect spectral ratio (\( S_M \)) as
Assumption \( H_\theta/V_\theta = 1 \) was verified by Nakamura experimentally using microtremor measurement at depth in a borehole. A more detailed about this method can be found in Lermo dan Chaves-Garcia [16, 17].

The H/V spectral ratio \( [T_{H/V} (\omega)] \) was obtained by dividing the averaged spectra of the horizontal components of the sediment site \( s_{NS}(\omega) \) and \( s_{EW}(\omega) \) by the spectrum of the vertical component \( s_V(\omega) \) of the sediment site:

\[
T_{H/V} (\omega) = \frac{s_{NS}(\omega) + s_{EW}(\omega)}{2 s_V(\omega)}
\]

3. Result and Discussion

3.1. Dominant Frequency \( (f_0) \) and Amplitude Maximum \( (A) \)

The dominant frequency of the area of Makassar and its surroundings have an interval of 1.11 - 18.69 Herz. Dominant frequency values for all measurement point were contours using the kriging interpolation method produced contour map distribution of dominant frequency \( (f_0) \) in the study area (figure 4). The high dominant frequency (over 10 Hz) is in the eastern part of Makassar City, which includes Manggala, Tamalanrea, western Panakkukang, eastern Somba Opu and Biringkana. These information matches with the geological information and Makassar's groundwater basin is relatively close to the base layer. Low frequencies (below 5 Hz) generally in the west, the area close to the coast, this area has relatively thick sediments.

Analysis of the result of H/V spectrum analysis can be seen that the research area has Amplitude Maximum of HVSR at intervals value of 1.14 - 15.03. Nakamura [13] uses the peak value of HVSR as a function of the amplification factor in case of earthquakes or periodic vibrations happen at that location. The lowest value was found at Batu Duang station and the highest were located at Permata Hijau residence station. In general, the low maximum amplitude value of the dominant frequency was in the eastern part of Makassar, meanwhile, the distribution of maximum amplitude can be seen in figure 4. The western part of Makasar City have a larger amplitude value, This means that the western part of Makasar City have a surface vibration with the low dominant frequency with high intensity.
This information is very important for geotechnical planning to avoid the same building frequency as the dominant frequency because it will cause resonance effect on the building.

3.2. Seismic Vulnerability Index (SVI)

SVI values can be obtained from the dominant frequency \( f_0 \) and Maximum amplitude \( A \), research areas has SVI value at interval value 0,14 - 158,31. The lowest value is at Batu Duang station and the highest are located at Permata Hijau and Singkabatu Residences stations. Generally, Makassar City and surrounding areas have SVI value below 60. SVI values in the western part of Makassar are below 10 while the western part is generally above 10. This means the western part is vulnerable to deformation, which means that this area is an unconsolidated sediment at the time of the earthquake.

Information on several destructive earthquake events, Nakamura [18] shows that areas that are often affected by major earthquake damage have an SVI value of between 20-100 whereas for non-destructive areas are completely in areas with SVI below 5. So this result shows the areas of the west of Makassar city is more vulnerable to damage than the eastern region.

![Figure 4. Contour map distribution of Seismic Vulnerability Index (SVI).](image)

4. Conclusion

The result of the dominant frequency distribution map provides information on the western (near shore) areas of Makassar has a thicker sediment compared to the west. This information also provides information on the planning of buildings to create buildings that have a frequency that is not equal to the dominant frequency in order to avoid resonance from vibrations generated from periodic vibration. Maximum amplitudes distribution map showed the intensity of the dominant frequency that occurs larger to the western part of Makassar City. This indicates that the area has a lot of vibrations with the dominant frequency it has. The western part of Makassar have a larger Seismic Vulnerability Index than others. In other words, the western part of the city of Makassar are more vulnerable to damage than the eastern region.

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