Determination of earthquake prone zones at university of tadulako based on dominant periods and peak ground acceleration (PGA)

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Abstract. University of Tadulako is the largest State University in Palu City. When an earthquake with a magnitude of 7.4 Mw on September 28, 2018, occurred, many buildings were damaged and even collapsed at that time, even causing casualties due to the rubble. Research on the Local Site Effect is essential for the assessment of seismic hazard. In this study, the local site effect was analyzed using the HVSR method based on microtremor data. The predominant Period (To) ranges between 1.709 s to 3.816 s, indicates that this area consists of alluvium and has a very thick sediment layer. Another parameter calculated in this paper is the peak ground acceleration (PGA) with values from 0.914 g to 0.924 g. This value is the first indicated soil damage level due to ground motions. The results of this study can be used as a consideration in the development of regional spatial planning and building structures based on earthquake analysis.

1. Introduction

The earthquake that occurred on 28 September 2018 caused various damage in various places in Palu City and its surroundings, including one of the state university in Palu City, University of Tadulako. The greatest strength of the earthquake at that time was reaching 7.4 mw, shaking with an epicenter distance about 70 km, causing damage to buildings on this university. The earthquake caused secondary disasters such as liquefaction, tsunami, landslides and collapsed buildings [7][20]. This following disaster caused humans to be injured even caused death. The collapsed building incident also occurred on a University of Tadulako, there were casualties due to the collapse of buildings. However, it turns out that not all university buildings collapsed during the earthquake, some buildings still survived well, some were cracked, badly damaged and even collapsed. This assumes that the level of damage to buildings is not fully influenced by the magnitude, epicenter distance and earthquake duration but also the characteristics of the soil at the local site [12]. Certain soil characteristics can increase the damage rates during the earthquakes [10].

One of the soil characteristic parameters that can be analyzed related to earthquake shocks and its impact on buildings is the dominant period. The method used to obtain the dominant period value in this study was by analyzing the HVSR curve from microtremor data. Similar studies that have been conducted before are research by Konno et al [11], Nakamura et al [15], Parolai, at al [17], Marjiyono [16], Kanai [2] and many more studies using dominant period to see the soil characteristics. According to [10], the HVSR method introduced by Nakamura is considered to be very economical and effective.
for studying the dynamic characteristics of the surface soil that cause the local site effect during an earthquake.

Another analysis to determine the impact of an earthquake on a local site that can be done is peak ground acceleration (PGA), the value of PGA is an important factor in determining amount of the impact of earthquake damage [22]. The PGA value can be determined through a ground acceleration measuring device or an accelerograph, but this method requires the absence of a lot of tools, time and costs [9], another way is by using an empirical approach that can provide PGA values according to the points needed [6] as presented in this paper. In this study, the empirical formula used was introduced by Fukushima and Tanaka [5] to determine the risk of vulnerability at the location based on the magnitude and hypocenter distance of the earthquake on 28 September 2020.

According to Cipta, et al. [4] in Abdullah [1] a fault in Palu City can provide earthquake risk to the X level scale Modified Mercalli Intensity (MMI) by the United State Geology Society (USGS) scale. Therefore, by analyzing the two parameters, both the dominant period and the PGA can be used as an evaluation material for the disaster-based development plan of University of Tadulako to reduce the risk if an earthquake occurs.

2. Method

2.1 Regional Geology

Based on a regional geological map by Sukamto, et al., [19] at 1: 25,000 scale, the regional stratigraphy of Palu City is divided into 4 units, which are the Tinombo Formation, Intrusive Rock Complex, Molasa Celebes, and Alluvium and Coastal Deposits. University of Tadulako itself is in 2 formations, namely the alluvium and molasa formation. The alluvium formation in the west and further to the east is a molass formation, the lithology of the two formations is sandstone and gravel. Alluvium and coastal sediment estimated to be in Holocene age consisting of gravel, sand, mud, and coral limestone, each formed in river, delta and shallow sea environments, which are the youngest sediments in this area [19].

Tinombo formation is the oldest unit in the study area. This formation is exposed in the west and east bunds. This formation also overlaps the metamorphic rock complex, the oldest rock in the Central Sulawesi region, inconsistently. Inside there are rubble originating from metamorphic rocks. These deposits consist of shale, conglomerates, sandstones, chert, and volcanic rocks, which are deposited in the marine environment. Near the intrusion there are slates and scraped rock and near the contact there are filites and quartzites. The western part of the bund contains the most sandstones and chert. Volcanic rock rubble is generally found in sandstones [19].

2.2 Horizontal perVertical Spectral Ratio (HVSR)

Collecting data in this study using the microtremor method that produces data signals, this signals then can be analyzed using the HVSR (horizontal per vertical ratio) method. This method is one of the easiest and cheapest methods to determine subsurface characteristics without damaging the surface. Technically, this data relies on a spectrum of ambient (micro seismic) vibrations that are spread over the earth's surface in the horizontal (North-South and East-West) and vertical (Up-Down) direction. The microtremor method was introduced by Kanai and Tanaka [8] to determine the local geological characteristics associated with the subsoil structure which is now developing and is used to identify the dominant period value at the site point. The HVSR technique itself was developed by Nakamura [14], he found that the resonant frequency increases linearly with the H / V ratio from the microtremor until a frequency peak is obtained. The H / V value is considered as the amplification of the ground motion at the measurement point.

As previously explained, the HVSR method analysis produces resonant frequency and ground motion amplification values. These two values can be used to analyze the geological character of the
local area related to the soil response that can damage buildings due to earthquakes. This value is obtained from the peak of the H / V ratio as in equation 1.

$$\frac{\text{H/V}}{m} = \left( \frac{(S_{NS})^2 + (S_{EW})^2}{S_{UD}} \right)^{1/2}$$  \hspace{1cm} (1)$$

where (H / V) \( m \) is the spectrum of the H / V ratio, \( S_{UD} \) is the spectrum of natural vibrations of vertical movement, \( S_{NS} \) and \( S_{EW} \) are two horizontal movements \[14\].

A simulation test was conducted by Lachet and Brad \[13\] which showed that the peak frequency value (dominant frequency) changes with variations in geological conditions. In this study, the value of the dominant period to be analyzed is obtained by equation 2.

$$T_0 = \left( \frac{1}{f_0} \right)$$ \hspace{1cm} (2)

Where \( T_0 \) is the dominant period of the soil and \( f_0 \) is the dominant frequency of the soil. The dominant period is the value of time when a microtremor wave travels from the surface through the sedimentary layer until it meets the bedrock or experiences reflection against its reflected plane \[21\]. Based on the value of this dominant period, the soil can be classified by Kanai classification as showed in table 1 \[2\].

**Table 1. Soil Classification based on the Soil Dominant Period \[2\]**

| Soil Classification | Dominant Periods | Kanai Classification | Explanation |
|--------------------|-----------------|----------------------|-------------|
| Type I             | 0.05 – 0.1      | Tertiary rocks       | The layer is not thick and consists of hard rocks (< 5m) |
| Type II            | 0.1 – 0.25      | Pebbly sand          | The layer’s thicknesses thicker than that of type I (5-10) |
| Type III           | 0.25 – 0.4      | Alluvial rocks and buff formation | The layer’s thickness is 10-30m |
| Type IV            | > 0.4           | Alluvial rocks formed from sedimentation | The layer’s thickness is very thick. |

In addition to the dominant period, this research also calculates the value of peak ground acceleration (PGA) which is the response of the maximum ground motion acceleration to earthquakes that have occurred in the sediment layer in that place. PGA is an important parameter to determine the impact of earthquake shocks \[3\]. PGA is expressed in g (gravity acceleration) in cm/s\(^2\) or gal, where 1gal is equal to 0.01 m / s\(^2\). The calculation of PGA in this study uses the Fukushima and Tanaka \[5\] as shown in equation 3.

$$\log \alpha = 1.3 + 0.41M_w - \log (R \cdot 0.32 \cdot 10^{0.41M_w}) - 0.0034 R$$ \hspace{1cm} (3)
Where: $\alpha$ is the peak ground acceleration value of the observation point in cm/s$^2$, $M$ is the Moment Magnitude and $R$ is the Hypocenter distance.

3. Results and Discussion

The dominant period value is obtained from the HVSR spectrum in Figure 1 through microtremor data collection. Figure 2 shows how the window selection is in accordance with the instructions from the Site Effects Assessment Using Ambient Excitations [18] in order to obtain a reliable HVSR curve that represents the subsoil conditions of the study area, this curve is obtained through equation 1. In this study, 14 points microtremor data were taken with a spacing of less than 250 meters. Figures 3a and 3b represent the results of the HVSR spectrum analysis of the study area. Points 6, 7, 8, 9, 10 and 12 have a curved shape like Figure 3a, which is a curve without a clear peak. While the other 8 points have a clear peak curve shape as shown in Figure 3b.

![Figure 1. 3 component data signals from microtremor measurement](image1)

![Figure 2. Window Selection](image2)
The information obtained from the HVSR curve is the value of the resonant frequency or the dominant frequency ($f_0$), then the dominant period value is calculated using equation 2. The calculation results show that the value of the dominant period varies from 1.709 s to the highest dominant period is 3.816 s. This indicates that the entire study area has a type 4 soil classification consisting of alluvial rocks formed from sedimentation, in accordance with the geological conditions of the research area based on[19] which states that this location consists of weathered alluvial and molasses. In addition, the value of the dominant period which is more than 0.4 indicates that the thickness of the sediment layer is very deep. Conditions like this are relatively dangerous for the buildings that stand on them.

Figure 4 is a map of the period dominant distribution values which provides an overview of areas that have the potential to cause more serious damage to buildings. The north and east sides of this area have a greater potential for building damage if an earthquake occurs compared to other locations. Building construction is recommended in areas with blue to green area on the map that have a lower dominant period value. Construction of buildings in yellow to red areas on the map should be avoided or strengthening the structure of buildings in these areas because of the higher risk location.
The PGA map in Figure 5 is the response of the ground to the earthquake that occurred on 28 September 2020 with a magnitude of 7.4 MW. The calculation of PGA value for Fukushima and Tanaka equation only depends on the hypocenter position and the earthquake magnitude. So that the value distribution pattern corresponds to the hypocenter distance of the earthquake at that time. This can be seen from the large PGA value in the north and smaller towards the south because it is farther from the epicenter. The PGA value in each location was not so significant, the difference was from 0.914 g to 0.934 g. The location which have high dominant period and high PGA value causes greater damage to buildings at the local site.

Figure 5. Map of Peak Ground Acceleration (PGA) distributions around the University of Tadulako

4. Conclusion
This study presents a brief result of the risk of soil vulnerability at University of Tadulako. Based on the HVSR analysis, the study area has a relatively high dominant period value varying from 1.7 s to 3.8 s and is associated with soil type 4 it means Alluvial rocks formed from sedimentation and The layer's thickness is very thick. Based on this, it can be said that the thickness of the sediment in the north and east of the study location is greater than the other locations. The PGA values did not vary much with the values from 0.914 g to 0.924 g. Earthquakes have the potential to occur in the future, evaluation of spatial plans and building structures at University of Tadulako is needed to reduce the risk of damage to existing building construction.

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