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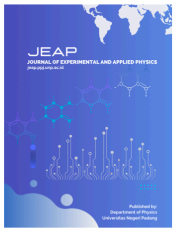

Microzonation of Seismic Vulnerability In Padang Panjang Timur Sub-District, Padang Panjang City Based on Microtremor Measurement

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Abstract: Padang Panjang City is one of the cities in West Sumatra which has a high level of risk of the natural phenomenon of earthquakes. This is due to the fact that it is traversed by the active Sumatran fault which can cause earthquakes at any time. The purpose of this study was to determine the value of the seismic vulnerability index in Padang Panjang Timur District, Padang Panjang City using microtremor measurements. This type of research is descriptive research, namely research that describes the symptoms or phenomena studied. The location for data collection was Padang Panjang Timur District, Padang Panjang City, West Sumatra Province. There are 15 data collection points, and the distance between points is 500 m. The microtremor method of measuring this microtremor can determine the dominant frequency value (f0), amplification factor (A0), and susceptibility index value (Kg). Microtremor data processing was used to obtain the H/V curve at each point of data collection using Geopsy software. The results of the microzonation of the seismic susceptibility index (Kg) ranged from 1.05 × 10^{-6} s²/cm to 170.09 × 10^{-6} s²/cm. High seismic vulnerability index values are found in the Koto Panjang Sub-District, Tanah Pak Lambik Sub-District, Guguk Malintang Sub-District, Ngalau Sub-District and Ganting Sub-District.

Keywords: Microzonation, Seismic Vulnerability Index, Microtremor, Padang Panjang City.

1. Introduction

One of the cities that are prone to seismic activity is the city of Padang Panjang. Padang Panjang City is one of the cities in West Sumatra that has a high level of risk for natural phenomena of the Sumatran active fault earthquake disaster at any time can cause earthquakes. To reduce the risk of casualties and damage caused by earthquakes, seismic microzonation is carried out. In the implementation, microtremor is applicable to observe the geophysical characteristic [1]. One of the methods that could be used to understand this is by mapping the seismic vulnerability index, which gotten by measuring microtremor in certain place [2].

Microzonation is an attempt to evaluate and map or describe potential disasters in an area, which are generally caused by strong ground shaking during an earthquake. These hazards include: amplification of ground motion, liquefaction, and potential for landslides [3]. Microzonation maps are used to describe potential natural disasters that will occur. If the microzonation map is combined with the microtremor data information of an area, it can be used to develop various natural disaster management strategies. One of the software that can be used to create microzonation maps is Surfer 13 software. This microzonation aims to determine the difference in shocks that may occur using microtremor recording data [4]. Microtremor is ground vibration with microtremor amplitude caused by natural or human factors [5]. The microtremor consists of a basic range of Rayleigh waves, presumably that the peak period of the microtremor H/V ratio provides the basis of the S wave period. The characteristics of microtremors are closely related to the soil structure conditions of the research area to determine the condition of the subsurface [6].

The data from the microtremor measurements in the field is ground vibration data in a function of time [7]. Microtremor utilizes the noise ratio around ground vibrations from human and natural activities on the horizontal and vertical components to describe subsurface structure [8]. The results of this microzonation indicate that when there is strong ground shaking, high damage is possible in areas with high seismic susceptibility. The information contained in the disaster map of a particular area cannot be used as a reference for evaluating other areas, because each region has its own disaster map according to the characteristics of the soil and rocks [5]. Seismic microzonation can be performed using microtremor measurements. According to Nakamura's assumption, H/V reflects the amplification level of the ground motion. By using this method, the measurement does not need to be carried out using the condition of the presence of hard rock. In general, the measurement of microtremors requires a seismograph or seismometer with three components that record the NS (north-south), EW (east-west), and vertical (up-down) components. In recording microtremors, direct measurements are made because what is recorded is a wave from nature, so it does not require an artificial source [9].

The seismic vulnerability index is an index that describes the level of vulnerability of the surface soil layer to deformation during an earthquake. The value of the seismic susceptibility index is obtained from the strain shift of the soil surface and its structure during an earthquake. Damage caused by an earthquake occurs when the earthquake force exceeds the limit of the strain, resulting in deformation of the surface soil layer [10]. The value of the seismic vulnerability index can be obtained from the relationship between the dominant frequency and the amplification factor and can also be obtained from measurements on the surface and changes due to the influence of the earthquake used to estimate an area. The vulnerability of the soil needs to be considered as well as the value of the strain shift (γ) in the soil layer during an earthquake. Under strain conditions, the seismic susceptibility index can be defined on a scale of $10^{-6}(\mathrm{cm}/s^2)$ [11]. The dominant frequency interprets the natural frequency in the area. This dominant frequency value often appears as the frequency value of the rock layers in the region so that the frequency value can indicate the type and characteristics of the rock [4].

Amplification is an earthquake wave that propagates from the bedrock to the ground surface. Earthquake amplification factor is an earthquake acceleration factor that occurs on the ground surface due to certain types of soil. The value of the amplification factor of a place can be known from the peak height of the HVSR curve spectrum as a result of microtremor measurements in that area [12]. Seismic vulnerability index is an index that describes the level of vulnerability of the ground surface during an earthquake [10]. The measured microtremor data can be used to determine the value of the seismic vulnerability index using the HVSR (Horizontal to Vertical Spectral Ratio) method. This method is a method that compares the spectrum ratio of the horizontal component of the microtremor signal to its vertical component. This can be known based on the soil classification and the dominant frequency values that have been grouped by Kanai as in Table 1.

Table 1. Soil classification according to Kanai is based on the value of the dominant frequency of microtremor [13]

Classification	**Dominant Frequency (Hz)**	**Kanai Land Classification**	**Soil Description**
Type I	< 2.5	Alluvial rocks formed from delta sedimentation, topsoil, sludge, etc.	The thickness of surface sediment is very thick
Type II	2,5-4	Alluvial rocks with a thickness of >5m. Consists of sandy sand-gravel, sandy hard clay, loam, etc.	Sediment thickness its surface goes deep category thickness of about 10-30 meters
Type III	4-6	Alluvial rocks with a thickness of 5m. Consists of sandy sand-gravel, sandy hard clay, loam, etc.	The thickness of its surface sediment falls into the intermediate category of 5-10 meters
Type IV	6-20	Tertiary rocks or older. Consists of Hard sandy rocks, gravel, etc.	The thickness of sediment is very thin dominated by hard rocks

Based on Table 1 that very low dominant frequency values can result in resonant effects and may also increase susceptibility to damage hazards over long periods. If the dominant frequency of the building is close to the natural frequency value of the base material in the area, the seismic vibrations will resonate with the building, increasing the stress on the building, causing damage during an earthquake. A high value of seismic vulnerability (Kg) means that the area is categorized as prone to earthquakes which is often determined on a layer of soil which is a soft sediment, on the other hand, if the vulnerability of the area is small, only small shocks occur during an earthquake, where this can occur. on soils that have rocks that have a strong and stable composition [13]. In determining the value of the seismic vulnerability index of an area, the geological conditions of the local area need to be considered. High seismic susceptibility index levels are usually found in areas with low resonance frequencies [10].

The HVSR method compares the vertical signal component with the horizontal signal component obtained from the measurement of the microtremor signal. The parameters generated in the HVSR method are the dominant frequency and amplification factor. The dominant frequency data and the amplification factor are used to determine the value of the seismic vulnerability index. The Kg value is the easiest vulnerability index to identify from the point of the measurement location. The value of Kg shows the measurement value used to determine the level of resistance or earth layer [14]. The value of the seismic vulnerability index can be obtained from the relationship between the dominant frequency and the amplification factor. The values of the amplification factor in a place can be determined from the peak height of the HVSR curve spectrum from microtremor measurements in that area. The classification of amplification factors according to Ratdomopurbo as in Table 2.

Table 2. Classification of amplification factor values [17]

Zone	Classification	Amplification Factor Value	Color in Mapping
1	Low	>3	Green
2	Medium	3 – 6	Blue
3	High	6 – 9	Yellow
4	Very High	≥9	Red

Based on Table 2 areas that have a low soil have little potential for damage during an earthquake. By using the seismic vulnerability index parameters, seismic microzonation mapping can be carried out to identify areas that are vulnerable to earthquake shocks[17].

2. Materials and Method

This type of research is descriptive of field data with measurements directly to the field as many as 15 measurement points. Data collection in Padang Panjang Timur District, Padang Panjang City used the HVSR (Horizontal to Vertical Spectral Ratio) method based on microtremor measurements. The data used in this study is primary data in the research area of Padang Panjang Timur District, Padang Panjang City with coordinates 0°27`33.0" - 0°28`30.4" South Latitude and 100°24`20.4" - 100°24`53.8" East Longitude. This microtremor data collection activity was carried out from 18 to 20 July 2022.

That seismic microzonation begins with determining the area or location of the study and establishing the problem to be studied first. Then based on these problems, the purpose of the research. Padang Panjang Timur Regency area is an area prone to earthquake disasters. The equipment needed in this research are Seismograph Sysmatrack MAE, S3S Sensor, Compass, Global Positioning System (GPS), and Laptop. This research begins with literature study, data collection, data processing, and data analysis. Microtremor recording results in the form of signal data in *sg.2 format. Data collection is data in the form of direct microtremor signal measurements in Padang Panjang Timur District, Padang Panjang City, measurements were carried out for 30 minutes to 50 minutes for each point.

The study begins with processing microtremor data using geopsy software which aims to obtain the values of dominant frequency (fo) and amplification factor (Ao). The results of the analysis using the HVSR method will produce an H/V graph of the dominant frequency and amplification factor which is then entered into the Kg formula so that the Kg value will be obtained. Nakamura's (1989) formula is in [15]:

$$K_g = \frac{{A_m}^2}{f_0} \qquad (1)$$

Where Kg is seismic vulnerability index value, A0 is amplification value, and f0 is dominant frequency value (Hz) Equation (1). The HVSR method compares the vertical signal component with the horizontal signal component obtained from microtremor signal measurements [16]. After that, seismic microzonation was carried out using Surfer 13 software. H/V curve which produces dominant frequency values and amplification factors used in calculating the seismic vulnerability index using Microsoft Excel, which was then continued with mapping using surfer 13 software. Several parameters mapped included dominant frequency, amplification value and seismic vulnerability index.

3. Results and Discussion

The results of microtremor data processing using Geopsy software with a total of 15 measurement points. The results obtained from data processing in the form of a graph curve HVSR (Horizontal to Vertical Spectrum Ratio). The results of this study are presented in the form of a dominant frequency distribution map, amplification factor, and seismic vulnerability index as a result of HVSR analysis based on microtremor measurements in Padang Panjang Timur District, Padang Panjang City. There are three components in the microtremor data, namely the horizontal component N-S (North-South), the horizontal component E-W (Easth-West), and the vertical component. Recorded data format saved in *.sg2 format. The microtremor data were analyzed using Geopsy Software, namely by windowing and cutting for signal selection without noise. Figure 1 the following is an example of microtremor data from measurements in the field.

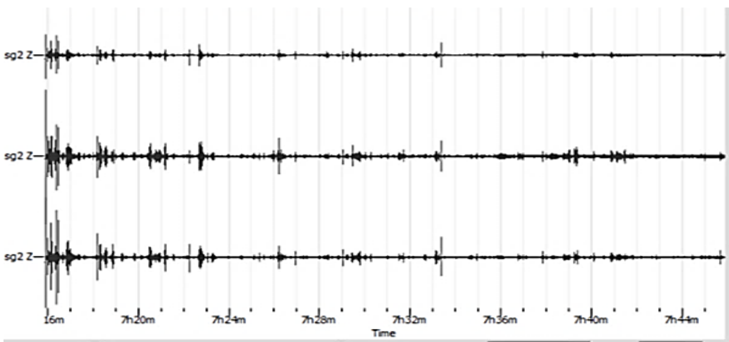


Figure 1. Microtremor Signal

The display of data from microtremor measurements, the results of these data measurements are recorded in three types of waves, namely vertical seismic waves (Up and Down), horizontal (North-South), and horizontal (East-West) based on Figure 1. Then in the software, the separation process between microwaves and noise recorded on the data is first carried out. This process is known as windowing as shown in Figure 2.

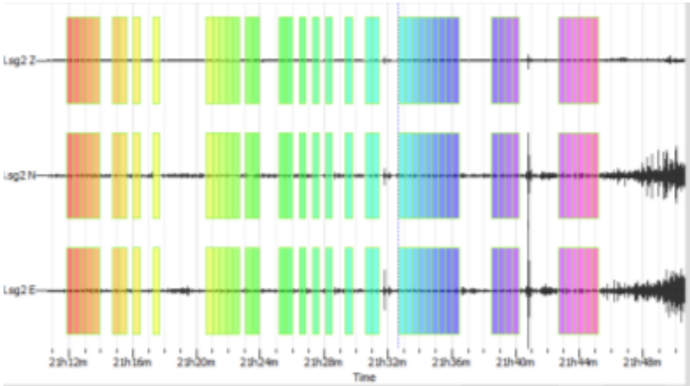
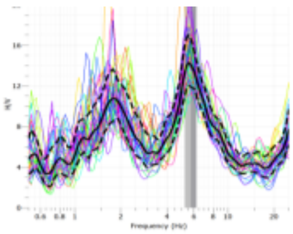
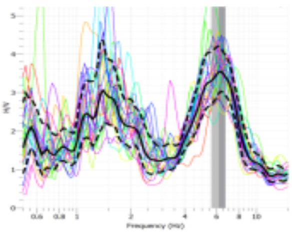


Figure 2. Number of Signal Windows

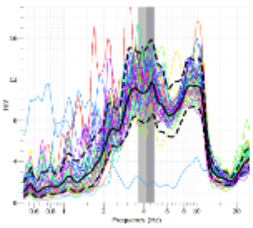
The process that is carried out automatically using input parameters in the form of window length, STA (short-term average), and LTA (long-term average) values in the H / V toolbox based on Figure 2. The determination of input parameters is carried out based on trial and error, where the value of the input parameter that can separate between microwaves and noise properly is the input value used. In addition, to improve the results of noise correction in the data, a manual windowing process is also carried out by selecting data that is considered noise manually based on daily records of measurements regarding activities around the measurement point (vehicle traffic and pedestrian activity). Based on the results of microwave processing from 15 research location points which after processing using the HVSR method and *Geopsy* software produced a graph of the relationship between H / V and frequency as shown in Figure 3.



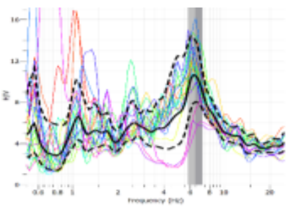
fo = 5,75 Hz***,*** ***Ao*** = 14,03



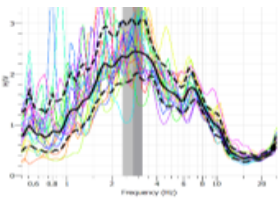
fo = 6,18 Hz, ***Ao*** = 3,53



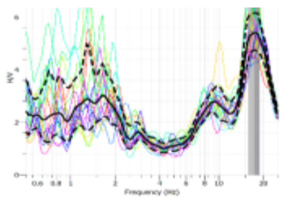
fo = 4,21 Hz***,*** ***Ao*** = 10,81



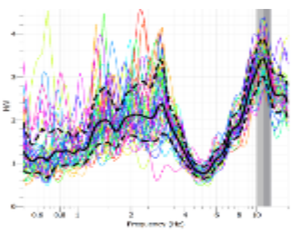
fo = 6,49 Hz***.*** ***Ao*** = 10,58



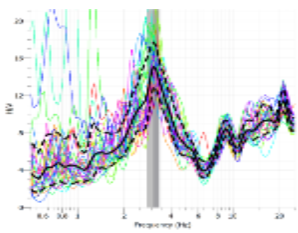
fo = 2,79 Hz***,*** ***Ao*** = 2,44



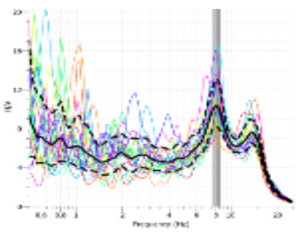
fo = 17,41 Hz, ***Ao*** = 5,40



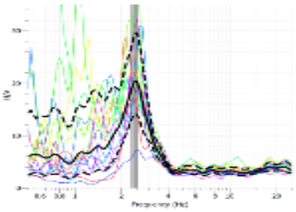
fo = 11,01 Hz***,*** ***Ao*** = 3,41

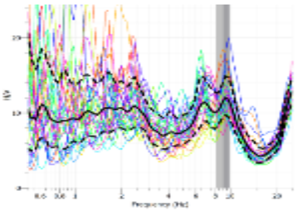


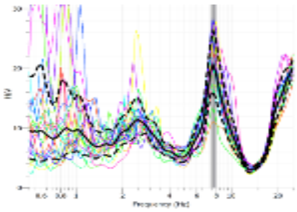
fo = 3,09 Hz, ***Ao*** = 15,08

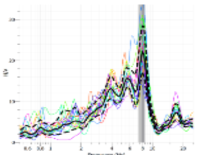


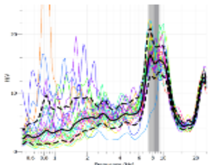
fo = 8,12 Hz, ***Ao*** = 10,34


fo = 2,42 Hz, Ao = 20,29


fo = 9,02 Hz, Ao = 11,61


fo = 7,67 Hz, Ao = 20,47


fo = 7,87 Hz, Ao = 21,58


fo = 8,27 Hz, Ao = 14,98

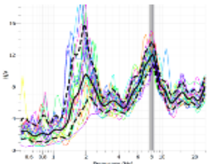

fo = 8,02, Ao = 11,99

Figure 3. HVSR Curve Results at Microtremor Measurement Research Sites 1 to 15

The results of the HVSR curve and data processing at the measurement point, spectrum analysis produces different HVSR curves based on Figure 3. This is due to the different geological conditions at each point of measurement. The HVSR curve is used to calculate the earthquake vulnerability value by comparing the amplification value and the dominant frequency contained as in the chart in the figure above. Based on the results of ambient wave analysis using the HVSR method at 15 variation points, from the dominant frequency values obtained during the study, a map of the distribution of the dominant frequency was made as shown in Figure 4.

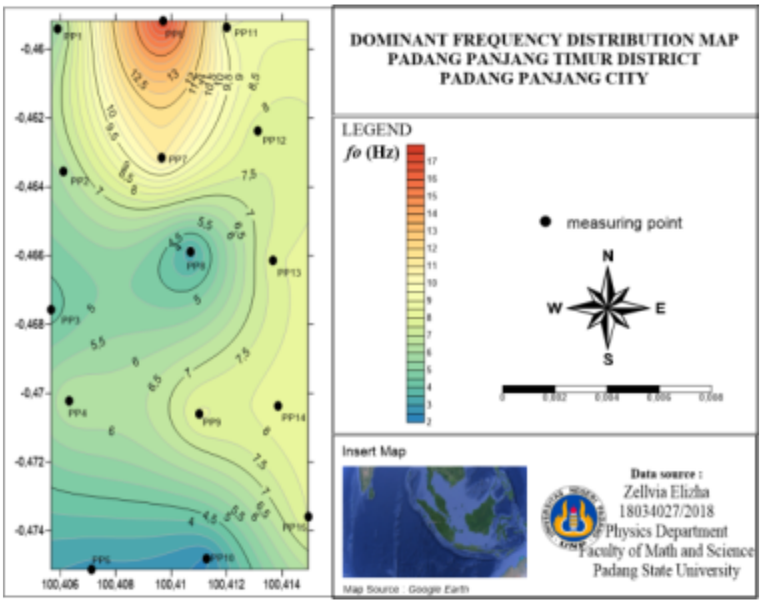


Figure 4. Map of The Distribution of Dominant Frequencies in Padang Panjang Timur District, Padang Panjang City

The results of the H/V analysis obtained the distribution of the dominant frequency values in Padang Panjang Timur District, Padang Panjang City which varied from the microtremor measurement data, namely 2,42 Hz to 17,41 Hz based on Figure 4. Furthermore, from the dominant frequency value (f0) and the amplification factor value (A0), the seismic vulnerability index (Kg) can be obtained using the formula in equation 1. Based on the results, it can be seen that value from the data processing is classified in the low to high-level category. Map of the distribution of dominant frequency values overlaid with Google Earth as shown in Figure 5.

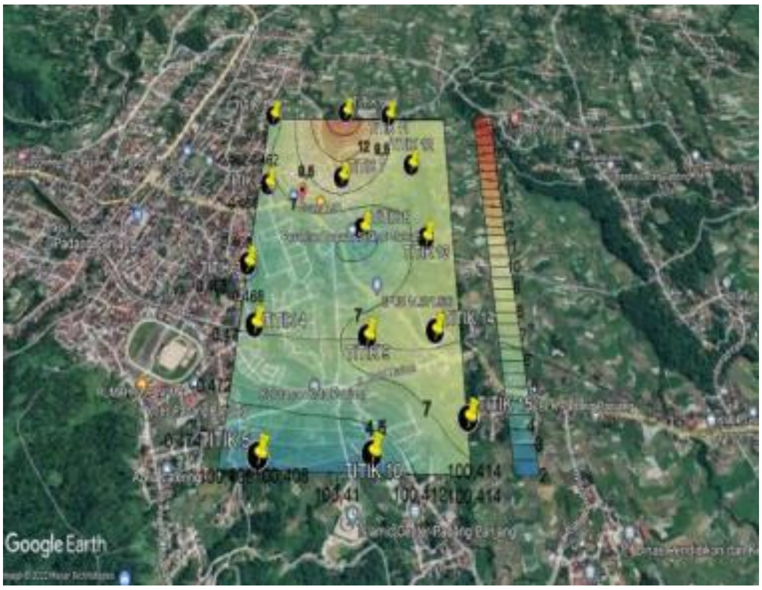


Figure 5. Map of The Distribution of Dominant Frequency Values
Overlaid With Google Earth

The dominant frequency value from low to highest is indicated by the color green, yellow, to red scattered throughout the area based on Figure 5. The amplification factor in Padang Panjang Timur District, Padang Panjang City, which was obtained during the study, was made a map of the distribution of the amplification factor as shown in Figure 6.

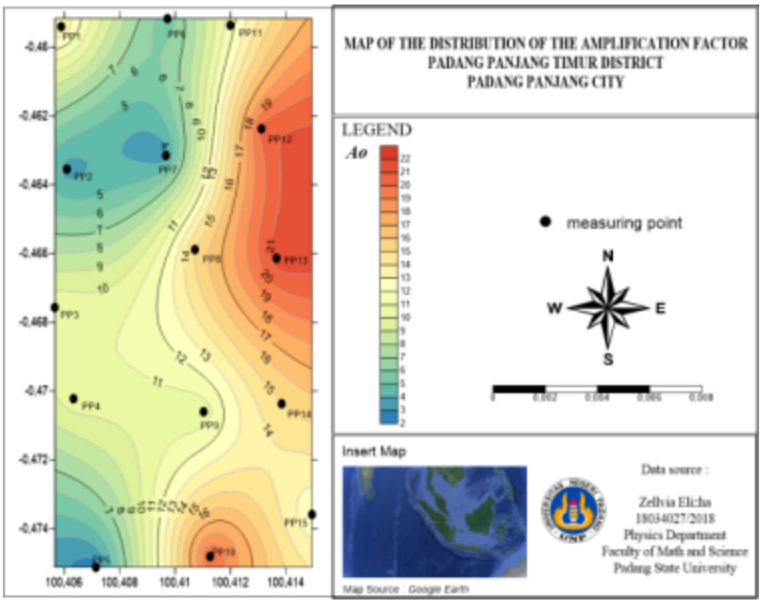


Figure 6. Map of The Distribution of Amplification Factors in East Padang Panjang District, Padang Panjang City

The results of the H/V analysis obtained the distribution of amplification factor values in East Padang Panjang District, Padang Panjang City which varied from the microtremor measurement data from 2,45 to 21,58 based on Figure 6. The distribution map of the amplification factor values overlaid with Google Earth is shown in Figure 7.

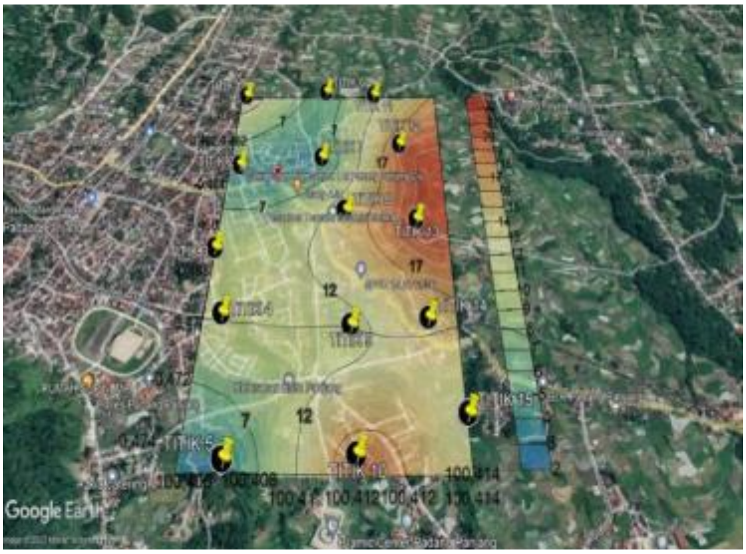


Figure 7. Map of The Distribution of Amplification Factor Values Overlaid With Google Earth

The distribution of amplification factors in East Padang Panjang District, Padang Panjang City is overlaid with Google Earth. On the H/V spectrum curve, the gain or amplification value can be known based on Figure 7. Amplification value Ao is obtained from the vertical axis of the top of the H/V curve. This amplification value will indicate the impedance contrast between the surface layer (soft sediment) and the bottom layer. This amplification value describes the internal structure of the soft sediment layer. The highest distribution of amplification factors in East Padang Panjang District ranged from 2,44 to 21,58. The highest amplification factor value is found in Ganting Village with an amplification factor value of 21,58. The lowest amplification factor value is found in Koto Panjang Village with an amplification factor value of 2,44.

Based on these values, three zones of amplification factors were obtained according to the classification of Setiawan [17]. Where the low category value (amplification value < 3) indicates that the area is a dense geological unit, the medium category (amplification value $3 \leq A < 6$) identifies that the measurement point is in a less dense geological unit area, and the very high category (amplification value $A \geq 9$) indicates that the measurement point is in a very dense geological unit area. A high amplification factor value indicates an area has a thick layer of sediment so that it is susceptible to more severe damage, due to the strengthening of earthquake shocks. The value of the amplification factor from low to highest is shown by green, yellow, and red colors scattered throughout the area in Figure 7. The high and low value of the seismic vulnerability index in Padang Panjang Timur District, Padang Panjang City which is influenced by the dominant frequency value and amplification factor, a seismic vulnerability index distribution map is made as shown in Figure 8.

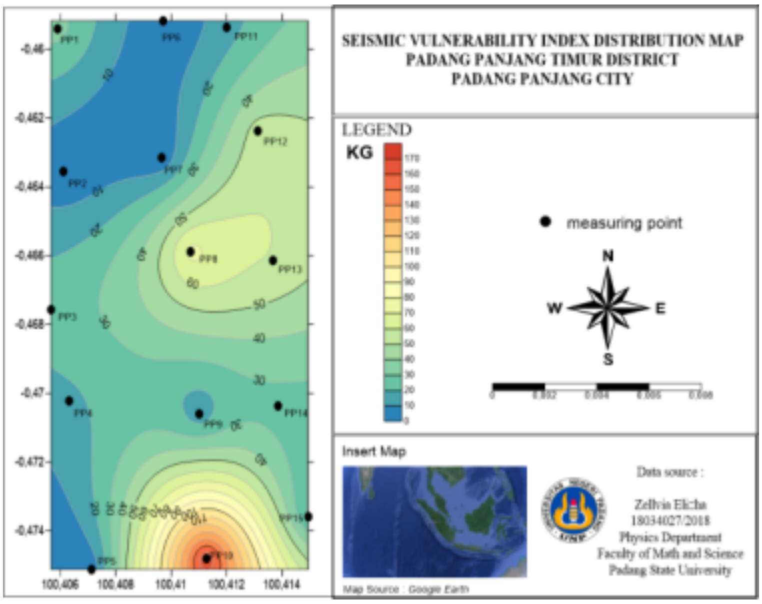


Figure 8. Map of Distribution of Seismic Vulnerability Index in East Padang Panjang District, Padang Panjang City

The results of the H/V analysis showed that the distribution of the seismic vulnerability index value of East Padang Panjang District, Padang Panjang City varied from the microtremor measurement data ranging from 1,05 x 10^{-6} s²/cm to 170,09 x 10^{-6} s²/cm based on Figure 8. The high seismic vulnerability index value is 170,09 x 10^{-6} s²/cm in Koto Panjang Village. This indicates that the area is the most vulnerable to the effects of an earthquake. The lower the value of Kg indicates that the area has solitary sediments. The higher the value of the seismic vulnerability index of an area, the greater the level of damage due to earthquakes, the smaller the value of the seismic vulnerability index, the smaller the potential damage due to earthquakes. Map of distribution of seismic vulnerability index values overlaid with Google Earth as shown in Figure 9.

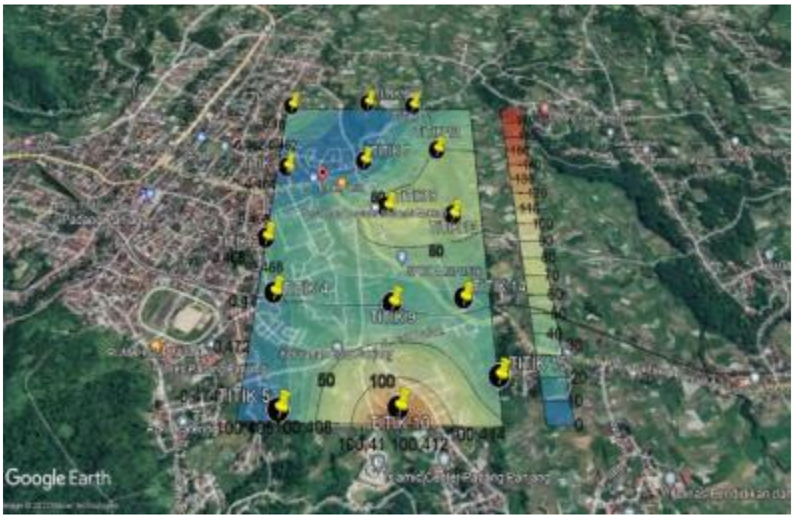


Figure 9. Map of The Distribution of Seismic Vulnerability Index Values Overlaid With Google Earth

A map of the distribution of seismic vulnerability index values, the research area of Padang Panjang Timur District, Padang Panjang City tends to have a low distribution of seismic vulnerability index values, which is shown in green based on Figure 9. Results of seismic vulnerability index data analysis at measurement points with varying values in categories from low to high. The high regional seismic vulnerability index values are at point 8, point 10, point 12, and point 13, namely in Koto Panjang Village, Ngalau Village, and Ganting Village which are shown in yellow to red. The area is a residential area, rice fields, and fields. The value of the seismic vulnerability index is related to the level of vulnerability of an area from the threat of earthquakes. The greater the value of the seismic vulnerability index of an area, the higher the risk of earthquake threats.

4. Conclusion

Based on the results of the research and discussion that has been carried out, it can be concluded that the seismic vulnerability value is calculated by the input value obtained from the parameters of the H/V curve analysis, namely the dominant frequency (fo) and amplification (Ao) parameters. The dominant frequency value in East Padang Panjang District, Padang Panjang City ranges from 2,42 Hz to 17,41 Hz. The amplification factor value of East Padang Panjang District, Padang Panjang City ranges from 2,44 to 21,58. The value of the seismic vulnerability index in East Padang Panjang District, Padang Panjang City ranges from 1,05 x 10^{-6} s^2/cm to 170,09 x 10^{-6} s^2/cm. Microzonation results of high seismic susceptibility index are found in the Koto Panjang, Guguk Malintang, Ngalau, and Ganting sub-districts. This shows that the area is the most vulnerable to the effects of an earthquake. Based on the analysis of seismic prone areas, the Padang Panjang Timur District, Padang Panjang City tends to be safe from seismic threats. However, for increased vigilance, the slightest risk must be taken into account.

Acknowledgments

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