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Vulnerability Analysis of Andalas University Library Building Using Microtremor HVSR Method

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This research aims to analyze the vulnerability of the Andalas University Library UPT Building which is located in an earthquake-prone area using the microtremor HVSR method. Measurements were taken at 20 points on each floor of the building to determine the natural frequency value, amplification factor, and seismic vulnerability index. The results show that the natural frequency values have a stable distribution pattern on most floors, with small variations on certain floors due to mass distribution or structural stiffness. The highest amplification values were found on floors 2 and 3, indicating the potential for local resonance. The highest seismic vulnerability index is on floor 2 with values up to 750, indicating the need for more attention to the design and structural strength of that floor. The HVSR method proved effective in analyzing the dynamic characteristics and potential vulnerability of buildings to earthquakes, providing important information for risk mitigation in disaster-prone areas.

Keywords: *Amplification, Natural Frequency, HVSR, Seismic Vulnerability Index*

1. INTRODUCTION

An earthquake is a shaking event caused by the collision of plates, fault activity, volcanic activity or rockfall. This type of disaster is destructive, can occur at any time and lasts for a short period of time. To design high-rise buildings, earthquakes are one of the most important reasons, as they cause shaking and swaying that can damage the building structure. Earthquakes are natural disasters that can cause damage to buildings, because they reduce the robustness and strength of the building. In the process of designing multi-storey buildings, earthquake factors must be taken into account because earthquakes cause shaking that can destroy building structures (Yuniarto, et al, 2021). One of the areas with high earthquake potential in Indonesia is West Sumatra. In this region, there are buildings that need to be designed with earthquake risk in mind, one of which is the Andalas University Library Building.

The Andalas University Library Building is a multi-storey building that has 5 floors and was built in an earthquake-prone area. The Andalas University Library Building is located in the Padang area, West Sumatra which has the potential for earthquakes and a fairly high building density, located in an area close to the Sumatra Fault to the west with a distance of ± 30-50 km, and the Mentawai Fault to the west precisely off the west coast of Sumatra with a distance of ± 100-150 km. Therefore, it is likely that this region is subject to earthquakes caused by these faults. On September 30, 2009, the city of Padang and most of West Sumatra were shaken by an earthquake measuring 7.6 on the Richter scale. This earthquake devastated buildings and included the Unand Library building which had just been prepared and had not yet been fully utilized.

Microtremor measurement is a passive seismic measurement to record vibrations generated by earth activity or human activity, usually this method is used to estimate the level of damage caused by

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earthquakes and can also be used to determine the condition of subsurface structures, strength and durability of building structures based on their dominant frequencies and amplification factors and resonance indices (Yuniarto, et al., 2021). The impact of wind effects on a building can be analyzed using microtremor data. The method used to analyze microtremors is the horizontal to vertical spectral ratio (HVSR) method because it has the advantage of being able to eliminate the source effect and does not depend on the availability of hard rock sites (Kumar et al., 2021).

The HVSR method has been used in research (Arintalofa et al., 2020) to analyze the subsurface characteristics of the Diwak and Derekan geothermal manifestations based on the Vp value. The results showed that the Vp value ranged from 390 m/s to 4,993 m/s. In addition, research by (Yuniarto, et al, 2021) used the HVSR method to analyze earthquake vulnerability in the ITS NU Pekalongan lecture building. The results of the study obtained the value of natural frequency and resonance index. Research (Kumar et al., 2021) also used the HVSR method to analyze local geological characteristics in Sikkim, India. From the research, it was found that the dominant frequency value ranged from 2.8 Hz-9.3 Hz, which showed that the smaller the dominant frequency value, the thicker the sedimentary deposits in the area. In research (Priadi, et al, 2024) to analyze the local site effect of the Mamuju city area as a disaster mitigation effort using the HVSR method. From the research, it was obtained that the Mamuju City area which is close to the coast has a potential vulnerability to earthquake hazards that is much higher, when compared to the area to the south.

The purpose of this research is to determine the natural frequency of the building and determine the natural frequency, amplification factor, and seismic vulnerability index of the UPT Perpustakaan Universitas Andalas building. As well as connecting the natural frequency and seismic vulnerability index of the building to determine the vulnerability of the UPT library building of the University of Andalas.

2. METHOD

This research was conducted in December 2024 at the Andalas University Library Building. The research methods included literature study, site survey, data collection, data processing, and data analysis. Microtremor measurements were conducted at 20 points on the library building which has five floors, with four points measured on each floor. The measurement duration at each point was 30 minutes. The equipment used in this research are geophones with three components (north-south horizontal, east-west horizontal, and vertical components), data loggers, connecting cables, compasses, and laptops. The software used were DataQ, Geopsy, Microsoft Excel, Notepad, and Surfer. The survey map of the study is shown in Figure 1.

Figure 1. Research location.

The study also includes a detailed survey map, which strengthens the spatial understanding of the measurements made. As revealed in seismic studies, noise interference from environmental sources can affect data quality (Larsen, 2023). While this study emphasizes the importance of precise measurements in seismic research, it is also important to consider potential limitations caused by environmental noise, which can obscure important data and affect the reliability of findings in seismic assessments (Rita, 2023).

2.1 Processing Data

The data obtained were analyzed using Geopsy software to determine the natural frequency and maximum amplitude values through the HVSR analysis method. To reduce or eliminate unwanted interference (noise) in the signal, a filtering process was performed during data processing to obtain the main relevant signal. The next step is to perform manual windowing, which separates the tremor signal from noise, such as disturbances caused by footsteps, vehicle or machine vibrations, and other human activities. After the windowing process is complete, the three signal components (North-South, East-West, and Vertical) are analyzed using the HVSR method based on the following equation:

$$HVSR = \frac{\sqrt{(X_{NS})^2 + (X_{EW})^2}}{X_{UD}} \tag{1}$$

where HVSR is the Horizontal to Vertical Spectral Ratio/amplification factor, XNS is the spectral fourier in the North-South direction, XEW is the spectral fourier in the East-West direction, and XUD is the spectral Fourier in the Up-Down direction After analyzing the HVSR, the natural frequency ($f0$) and amplification ($A0$) values will be obtained. In addition, the seismic susceptibility value (Kg) will also be obtained which can be determined using the equation:

$$K_g = \frac{(A_0)^2}{f_0} \tag{2}$$

where (Kg) is the seismic vulnerability index, ($A0$) is the amplification factor and ($f0$) is the natural frequency (Hz). The results of measurement data processing were used to create zoning maps of natural frequency, amplification factor, and seismic vulnerability index using Surfer 10 software.

3. RESULTS AND DISCUSSION

3.1 Natural Frequency (f0)

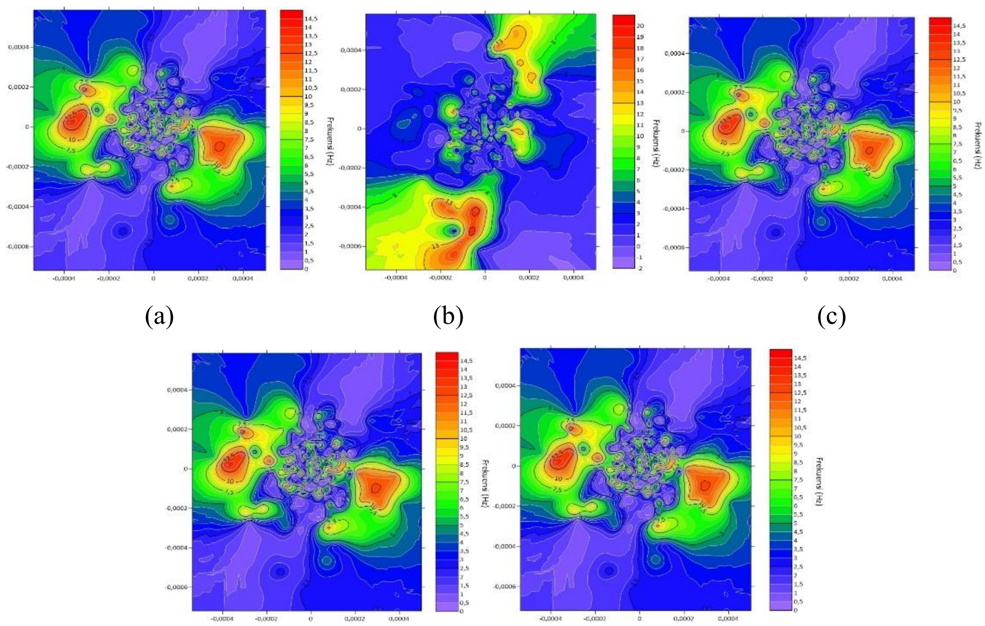
The value of natural frequency is one of the important aspects in building dynamics studies, especially in evaluating the structure's response to vibration. Natural frequency describes the intrinsic ability of a structure to oscillate freely when exposed to disturbances, such as earthquakes or environmental vibrations. In this study, the natural frequency values were analyzed on five floors of a library building with a microtremor approach using the HVSR (Horizontal to Vertical Spectral Ratio) method. After the measurement, the natural frequency value for each floor can be seen in Table 1.

The results of natural frequency interpretation are presented in the form of contour maps that provide an overview of the distribution of natural frequency values on each floor of the Andalas University library building can be seen in Figure 2.

Based on the tabular data and contour maps, the natural frequency values show varying distribution patterns on each floor. On the first floor, the natural frequency value is dominated by 4.238 Hz, with a relatively uniform distribution across the floor area. This indicates that the ground floor has a stable dynamic response to vibration. On the second floor, the natural frequency value is still dominated by 4.238 Hz, but there is a variation at one of the measurement points that reaches 4.307 Hz, as shown in the contour map. This indicates that there are variations in the characteristics of the floor structure that can affect the vibration response. On floor 3, the natural frequency value varies between 4.223 Hz to 4.238 Hz, as seen from the data and contour map. This pattern indicates that the 3rd floor has more complex dynamic characteristics than the floors below, with the potential for uneven mass or stiffness distribution. On the 4th floor, the natural frequency values mostly remain at 4.238 Hz, although there are small differences seen in the contour map distribution. This indicates that the 4th floor still has fairly stable response characteristics, but small variations in the value distribution may reflect potential areas of greater response. And on the 5th floor, the natural frequency value is again dominated by 4.238 Hz with a uniform distribution pattern like the 1st floor. This indicates that the top floor has a dynamic response that is again stable. Overall, the natural frequency distribution pattern from floor 1 to floor 5 shows stability at 4.238 Hz in most areas, with floor 2 and floor 3 having slight variations in values caused by differences in mass distribution, structural stiffness or interaction of structural elements on the floor.

Table 1. Classification of Natural Frequency Values

No	Data Acquisition Points	Latitude	Longitude	Frequency (Hz)
1.	LT1.1	0.00000672	0.0000121	4.238167529
2.	LT1.2	0.00000522	0.0000231	4.238167529
3.	LT1.3	-0.00001030	-0.0000880	4.238167529
4.	LT1.4	-0.00001400	-0.0000339	4.238167529
5.	LT2.1	0.00002070	0.0000282	4.238167529
6.	LT2.2	0.00000230	-0.0000336	4.238167529
7.	LT2.3	0.00005040	0.0000445	4.307437492
8.	LT2.4	-0.00000144	0.0000152	4.238167529
9.	LT3.1	0.00000416	0.0000287	4.238167529
10.	LT3.2	0.00000902	0.0000151	4.222954051
11.	LT3.3	-0.00001620	0.0000137	4.223742964
12.	LT3.4	0.00003030	0.0000491	4.222954051
13.	LT4.1	0.00001030	-0.0000303	4.222954051
14.	LT4.2	-0.00000566	0.0000178	4.238167529
15.	LT4.3	0.000000442	0.0000294	4.238167529
16.	LT4.4	-0.00000734	0.0000161	4.238167529
17.	LT5.1	0.00000248	0.00000301	4.238167529
18.	LT5.2	0.00001490	0.00000911	4.238167529
19.	LT5.3	0.00003070	0.0000341	4.238167529
20.	LT5.4	0.00001640	0.0000173	4.238167529



(a) (b) (c)

(d) (e)

Figure 2. Distribution map of natural frequency values around the Andalas University Library area (a) 1st floor natural frequency; (b) 2nd floor natural frequency; (c) 3rd floor natural frequency; (d) 4th floor natural frequency; (e) 5th floor natural frequency.

3.2 Amplification (A_0)

Amplification in seismic studies refers to the increase in seismic wave amplitude at a particular location, which can be calculated using the Horizontal to Vertical Spectral Ratio (H/V) method. This technique is very important in analyzing microtremor data to evaluate site-specific amplification factors, especially at dominant frequencies. The following is an explanation of the main aspects of amplification obtained from microtremor analysis.

The amplification factor is calculated from the H/V ratio at the dominant frequency (fo), which reflects the geological characteristics of the site (Arifin, 2014). The H/V technique has been refined to include both peaks and valleys in the spectral ratio, resulting in a more reliable estimation of the amplification factor (Konno & Ohmachi, 1998). Microtremor analysis is essential for urban planning and disaster risk reduction, especially in areas with historical seismic activity (Arifin, 2014).

The integration of microtremor data with synthetic earthquake models enables a comprehensive understanding of ground dynamics and amplification effects (Syahbana et al., 2018).

Although the H/V method is widely used, its theoretical foundations are still debated, indicating the need for further research to improve its reliability and applicability in various geological contexts.

Table 2. Amplification value classification

Zones	Calcifications	Amplification Factor Value
1	Low	$A_0 < 3$
2	Medium	$3 \leq A_0 < 6$
3	High	$6 \leq A_0 < 9$
4	Very High	$A_0 \geq 9$

The amplification factor (AF) is very important for evaluating site effects, especially in urban areas where soil conditions can exacerbate seismic impacts (Vessia et al., 2007). Techniques such as the Horizontal to Vertical Spectral Ratio (HVSR) method are used to estimate AF, which shows variations based on geological structure (Dec, 2011). Studies on the Batubesi dam used the Nakamura method to determine the AF value, which showed a range from 1.35 to 11.5, indicating significant site amplification (Sunaryo, 2017).

Soil parameters, including resonant frequency (fo) and shear wave velocity, strongly influence AF. Research shows that a combination of these parameters provides more accurate predictions of AF (Zendagui et al., 2017). The complexity of the soil profile requires advanced modeling techniques, such as Generalized Regression Neural Networks, to better understand AF variations (Zendagui et al., 2017). Although amplification factors provide important insights into seismic vulnerability, it is important to consider that not all sites show significant amplification effects, as some sites may have minimal site response due to geological stability (Dec, 2011).

Amplification is also affected by the interaction between subsurface structures and seismic waves. Research shows that soft soils overlying bedrock tend to amplify the wave amplitude, especially at certain frequencies that correspond to the resonance frequency of the soil. The overall amplification values at each data acquisition point can be seen in Table 3.

In Figure (3) showing the average amplification contour map shown above, the amplification values on the five floors of the Andalas University Library show a varied distribution. From the data table, it can be seen that the amplification values range from 7 to 17.9, with an uneven distribution pattern on each floor. On the contour map, there is an area with high amplification concentrated on the 2nd floor and 3rd floor which is marked with an amplification value close to 17.5 seen on the map with a red to orange color gradation. These areas are due to a greater concentration of vibration energy, which may be influenced by the stiffness of the structure, the unevenly distributed mass, or the geometry of the building in these areas.

Lower average amplification values, ranging from 7 to 11, are seen over a larger area of the contour map at floors 1, 4 and 5, indicating that most structures have a more stable dynamic response to vibration. However, areas of high amplification can be indicative of potential local resonances that pose a risk to the stability of the structure.

Table 3. Classification of Amplification Values at the research location

No	Data Acquisition Points	Latitude	Longitude	Amplifikasi (A_0)
1.	LT1.1	0.00000672	0.0000121	11.2445
2.	LT1.2	0.00000522	0.0000231	3.27149
3.	LT1.3	-0.00001030	-0.0000880	10.4416
4.	LT1.4	-0.00001400	-0.0000339	9.22886
5.	LT2.1	0.00002070	0.0000282	9.22886
6.	LT2.2	0.00000230	-0.0000336	9.45958
7.	LT2.3	0.00005040	0.0000445	17.9760
8.	LT2.4	-0.00000144	0.0000152	12.7221
9.	LT3.1	0.00000416	0.0000287	11.8137
10.	LT3.2	0.00000902	0.0000151	12.0495
11.	LT3.3	-0.00001620	0.0000137	11.1936
12.	LT3.4	0.00003030	0.0000491	12.6583
13.	LT4.1	0.00001030	-0.0000303	12.3502
14.	LT4.2	-0.00000566	0.0000178	11.2445
15.	LT4.3	0.000000442	0.0000294	13.3661
16.	LT4.4	-0.00000734	0.0000161	7.20957
17.	LT5.1	0.00000248	0.00000301	10.9702
18.	LT5.2	0.00001490	0.00000911	10.9702
19.	LT5.3	0.00003070	0.0000341	9.69607
20.	LT5.4	0.00001640	0.0000173	13.7003

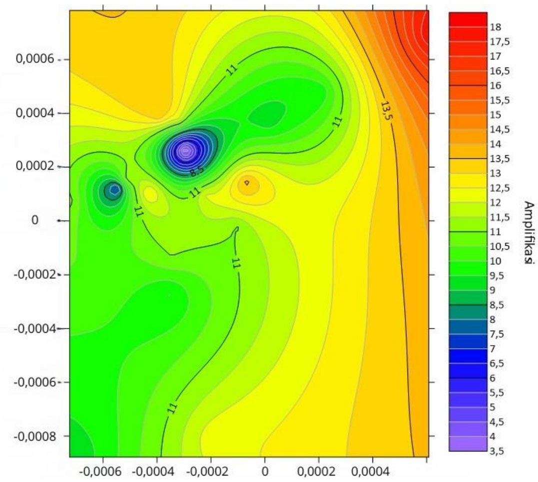


Figure 3. Distribution map of amplification values around the Andalas University Library area.

3.3 Seismic Susceptibility Index (Kg)

The seismic vulnerability index (Kg), also known as the earthquake vulnerability index, indicates the extent to which the surface soil is susceptible to deformation during an earthquake. Based on formulas and calculations, the value of this index is affected by the maximum amplitude and natural frequency of the soil. If the amplitude is large and the natural frequency is small, the seismic vulnerability index will be higher. Conversely, it will be lower if the amplitude is small and the natural frequency is high. The unit of susceptibility index is expressed in Kg (x 10^6 s^2/cm). Research by Nakamura (2000) found that areas with high damage tended to have vulnerability index values of more than 10 x 10^6 s^2/cm, while areas with minimal damage had values less than this figure. Based on measurements at 20 points in the Andalas University library building, the distribution of seismic vulnerability index values is shown in Figure 4.

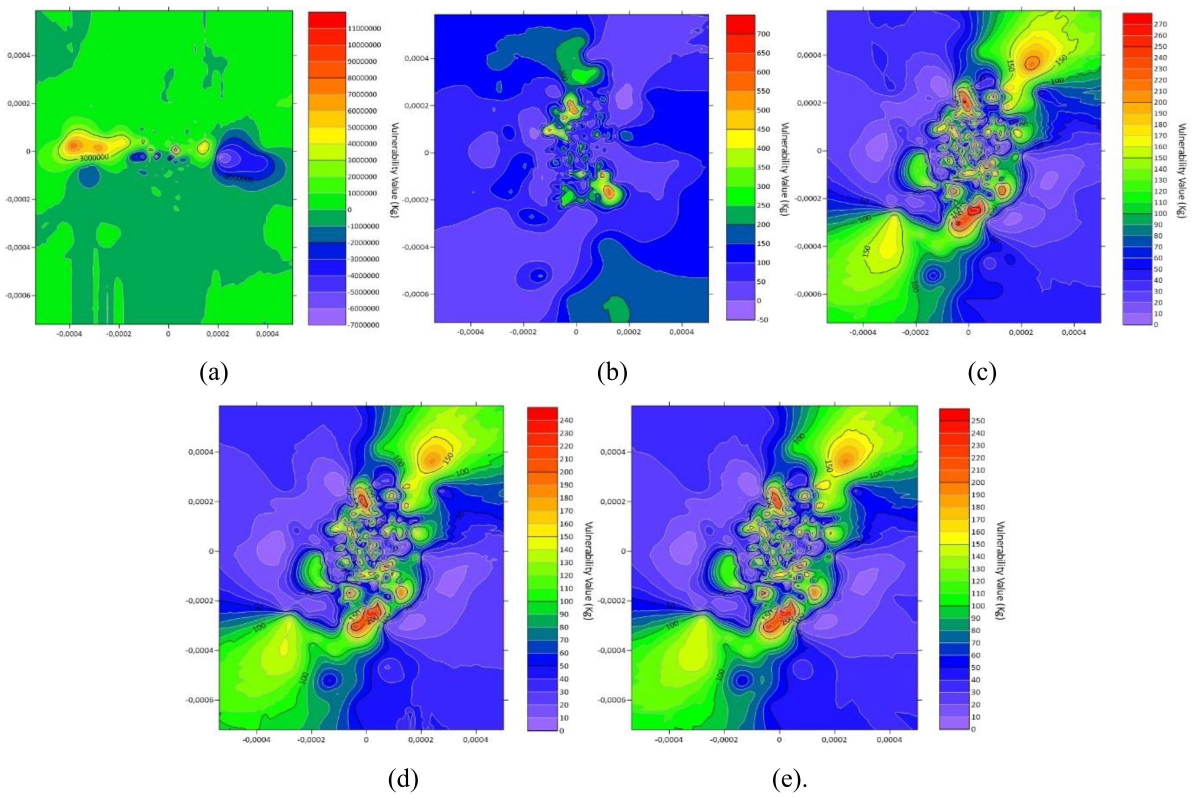


Figure 4. Distribution map of seismic vulnerability index values around the Andalas University Library area. (a) Seismic Susceptibility Index of the 1st floor; (b) Seismic Susceptibility Index of the 2nd floor; (c) Seismic Susceptibility Index of the 3rd floor; (d) Seismic Susceptibility Index of the 4th floor; (e) Seismic Susceptibility Index of the 5th floor.

Building vulnerability data is influenced by amplification, natural frequency of the soil in the building and the height of the building itself. Based on the data, it can be seen that the value of the vulnerability index on each floor is different. The vulnerability value shows a varied distribution pattern on each floor. Based on the vulnerability value obtained on the building shows a fairly high level of vulnerability. The first floor area of high vulnerability (red zone) is concentrated in the center of the map, with the highest value of about 140 kg. This indicates an area on the first floor that is vulnerable to deformation or damage from external loads. This area requires attention to reduce the risk of dynamic resonance. On the second floor area, the distribution of vulnerability is more dispersed than on the first floor, with the maximum value reaching 750 kg. This indicates an additional load or risk on this floor. The change in vulnerability distribution may be due to variations in structural stiffness on this floor. On the third floor, the vulnerability value decreases with a maximum of 300 kg, but the vulnerability pattern still shows critical areas in the red zone. This floor tends to have a more uniform stiffness than the floors below. This area shows a reduction in amplification due to a more even load distribution. The fourth and fifth floor areas have similar vulnerability values to the third floor area. The fourth floor area maximum value in the red zone is 240 kg, lower than the second floor (750 kg) but higher than the first floor (140 kg) and third floor (300 kg). This pattern indicates a transition from high risk on the lower floors (due to larger lateral forces) to a more uniform risk level on the upper floors. The amplification on this floor is still significant but smaller than on floor 2. This could be attributed to a better distribution of structural stiffness or a reduction in lateral forces at the top of the building. The red zone area indicates possible local amplification due to stiffness inhomogeneity at that floor. In the fifth floor area the maximum value of the red zone is 260 kg, slightly higher than the fourth floor but still far below the second floor (750 kg). The higher vulnerability pattern at this floor may be due to factors such as the influence of wind loads or the end condition of the structure (boundary effect). The amplification on these floors is relatively small compared to the lower floors, especially floor 2 which shows the highest amplification peak. However, the presence of red zone values indicates localized risks in certain areas that require additional strengthening or attention. Based on the building vulnerability value, this is proportional to the amplification so that the greater the amplification in a building, the greater the building vulnerability index.

4. CONCLUSION

This study successfully analyzed the vulnerability of the UPT Library Building of Andalas University using the microtremor HVSR method. The natural frequency value shows a stable distribution pattern on most floors, with slight variations on certain floors due to mass distribution or structural stiffness. This study shows that the Andalas University Library building has a stable natural frequency on most floors, with a dominant value of 4.238 Hz. However, there are small variations on the 2nd and 3rd floors, indicating uneven mass distribution or structural stiffness. Amplification values range from 7 to 17.9, with areas of high amplification concentrated on floors 2 and 3, indicating a greater concentration of vibration energy on these floors.

The highest seismic vulnerability index is found on floor 2 with values between 700-750, indicating that this area requires special attention in structural strengthening. The lowest vulnerability value is found on the 1st floor (135-140), while the other floors have vulnerability values ranging from 200-300. These findings show that high amplification contributes to an increase in the seismic vulnerability index, so the higher the amplification, the greater the risk of building vulnerability to earthquakes.

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