Microzonation Mapping in Supporting Construction Plan, New Capital City of Indonesia (Case Study: Sepaku Sub-district, Panajam Paser Utara Regency)

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Abstract. Determination of East Kalimantan, particularly Sepaku Sub-District, Panajam Paser Utara Regency, and Kutai Karta Negara Regency as the New Capital City of Indonesia requires an in-depth and comprehensive study of various aspects, including the natural disaster of the earthquake. Based on earthquake records for the last 11 years, East Kalimantan is the province with the highest level of seismicity in Kalimantan Island, and nationally it occupies 26th rank. The existence of the local Meratus fault needs to be watched for because it lies beneath the land and is relatively active. It has the potential to damage areas with high seismicity levels. The potential for earthquake damage can be minimized by constructing earthquake-resistant infrastructure. The construction of earthquake-resistant infrastructure can be started by studying soil dynamics properties in the area, like natural frequency and peak ground acceleration. This research was conducted by applying the Horizontal-to-Vertical Spectral Ratio (HVSR) method to analyze both properties to calculate the vulnerability index through a microzonation study. The HVSR method is comparing the ratio of the spectrum of the horizontal component of the microtremor signal with its vertical part. The HVSR method utilizes the natural harmonic vibrations of the soil caused by natural activities. The result of the research on the study area shows an index of seismic vulnerability ranges from 0.2 to 2.1.

Keywords: Microtremor · HVSR · Natural Frequency · Amplification · Vulnerability Index

1 Introduction

The relocation of Indonesia's Capital City (IKN) is one of the government's essential projects of the National Medium-Term Development Plan for 2020–2024 [1]. The issue of IKN transfer itself has long been a government debate, but since 2017 the Ministry of National Development Planning (Bappenas) has intensively reviewed it. Furthermore,

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in 2019, President Joko Widodo officially announced the relocation of IKN to East Kalimantan, specifically the Sepaku sub-district, Penajam Paser Utara, and Kutai Kartanegara regency.

Determining IKN migration from Jakarta to East Kalimantan requires a comprehensive study to anticipate potential disaster risks, including earthquakes. Based on observation statistics of tectonic earthquake incidences in each province of Indonesia for 11 years from 2009 to 2019, East Kalimantan is the province of Indonesia located on Kalimantan island with a relatively high level of seismicity, and the rank is 26 nationally [2]. In addition, in March 2022, an earthquake hit Paser Regency. The earthquake's epicenter was on the mainland at a depth of 10 km with a magnitude scale of 4.5 [3]. The earthquake is thought to have originated from three fault zones on the island of Kalimantan, namely the Tarakang Fault, Mangkalihat Fault, and Meratus Fault. Meratus Fault is a local fault directly adjacent to the new IKN. The existence of the Meratus fault, which is local, located on land, and relatively active, needs to be watched out for because it has the potential to damage areas with high seismicity levels.

In order to reduce the risk of damage to building infrastructure because of earthquakes by developing strong buildings earthquake-resistant. A map representing areas with a high earthquake vulnerability index is needed to create earthquake-resistant structures. This map can assist in spatial planning and regional locations, including the Sepaku Sub-District and Penajam Pasar Utara Regency, as part of the IKN Area. The seismic susceptibility index can be investigated by seismic microzonation studies using the horizontal-to-vertical spectral ratio (HVSR) method as a parameter of the potential risk of local earthquake damage. The HVSR method utilizes the natural harmonic vibrations of the soil caused by natural activities. The HVSR method compares the spectral ratios of the horizontal and vertical components of the microtremor signal. Studies on microzonation using the HVSR method have been carried out by several researchers [5–8].

2 Material and Methods

2.1 Microtremor and HVSR Method

Microtremor is a natural ground vibration with a frequency range of 0.5 Hz–20 Hz. Microtremor can also be interpreted as a short period of vibration produced by several sources, both natural origin, such as ocean waves, the influence of wind on trees and buildings, and vehicular traffic, as well as those originating from human activities. Measurement of the natural vibration of the soil is needed to determine the two main parameters, namely the dominant frequency of the soil (f_0) and the amplification factor (A_0) value. Research related to microtremors was first introduced by Omori in 1908, then developed by Kanai and Tanaka in 1961 by proposing microtremor application engineering, and in 1989 Nakamura developed and popularized the Horizontal To Vertical Spectral Ratio (HVSR) technique, so it was called the Nakamura HVSR method. [10]. The HVSR method compares the spectrum ratio of the horizontal component of the microtremor signal to its vertical part [7, 11, 14].

Natural Ground Frequency (f_0). The magnitude of the natural frequency represents the frequency that often appears in the study area to show the types and characteristics of rocks [15]. The value of the natural frequency of the soil is determined by the thickness of the sediment layer and the average subsurface velocity (***Vs***) [11]. Mathematically it can be shown in Eq. (1).

$$f_0 = \frac{v_s}{4H} \tag{1}$$

Amplification Factor (A_o). Amplification of seismic waves occurs because of the disturbance from another wave with the same frequency to an object with a self frequency. Amplification of earthquake waves occurs when the wave propagates to the ground surface where the soil's natural frequency (f0) has a frequency value that is almost equal to or has the same frequency as the incoming earthquake. Amplification is an event that strengthens a wave when it passes through a particular medium. The ratio of the characteristics of the horizontal signal to the vertical signal is directly proportional to the gain of the wave when it passes through a medium [7].

2.2 Seismic Vulnerability Index (Kg)

The Seismic Vulnerability Index (K_g), which is often referred to as the earthquake vulnerability index, is a description of the deformation of the vulnerability level of the surface soil layer during an earthquake. The seismic vulnerability index is strongly influenced by the maximum amplitude and natural frequency of the soil in an area [12]. The seismic susceptibility index value will be even more significant when the amplitude value is immense, and the natural frequency value is small. On the other hand, if the amplitude value is small and the natural frequency value is more significant, then the earthquake vulnerability index value will be smaller [6, 7]. The value of the seismic vulnerability index (K_g) in an area can be determined using Eq. (2) [7].

$$K_g = \frac{A_o^2}{f_o} \tag{2}$$

This research was conducted in Sepaku sub-districts, Penajam Paser Utara Regency, East Kalimantan (Fig. 1). This area is included as a development center of the new capital city of Indonesia. Microtremor measurements were conducted at 17 measurement points spread over the area. The research area is focused on the main areas that will be soon processed as building supporting facilities and road infrastructure.

Microtremor data were measured using a broadband sensor with a frequency range of 0.1 to 50 Hz. This instrument uses three sensor components, namely two horizontal components and one vertical component. The measurement durations at each point were around 30 min to obtain sufficient microtremor recording data for processing. In addition, based on the standard rules for getting recorded data with a frequency of 0.1 Hz, the minimum measurement duration must be 30 min (Sesame). The supporting instrument used in this study is GPS which is used to find measurement points.

The initial stage in this research is to design a measurement survey according to the research area (Fig. 1). Based on the survey design that has been made, microtremor measurements are carried out by setting the instrument (Fig. 2). The sensor is set in a balanced condition using a spirit level to measure all components of waves correctly.

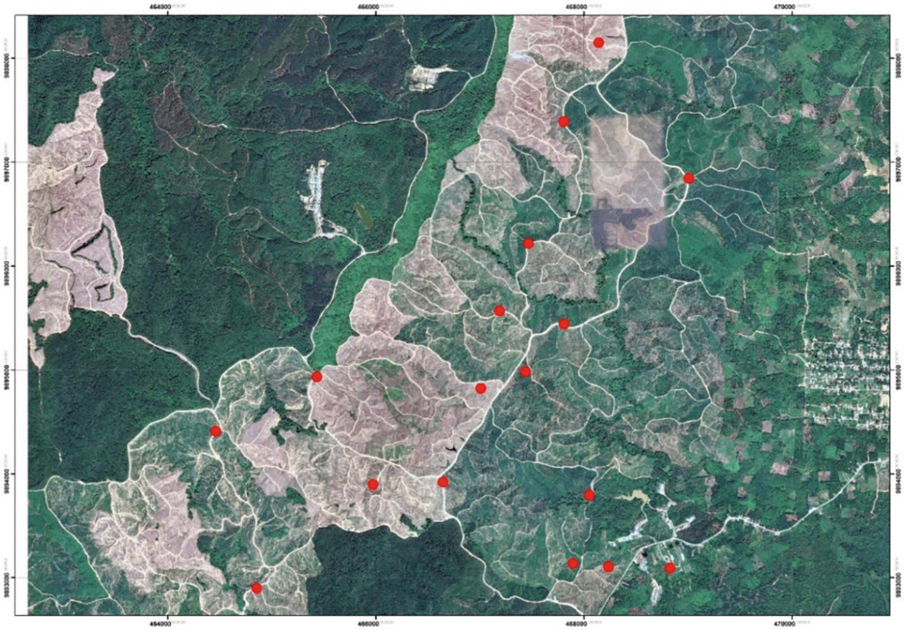

Fig. 1. Research site map and red marks indicate microtremor measurement points.

The measurement point was located as far as possible from crowds and large trees to avoid any disturbances recorded during the data collection process in the field. The next stage is determining the natural frequency and amplification factor of the soil by performing the data processing as well as the seismic vulnerability index of the research area. Processing was done by filtering the recorded data to eliminate interference signals using a bandpass filter. The next stage interpolated natural frequency, amplitude, and seismic vulnerability index data to obtain a distribution map throughout the research area.

3 Results and Discussion

In this study, microtremor was measured by measuring minimal ground vibrations with continuous intensity generated from various vibration sources. Micro tremor can be interpreted as a natural harmonic vibration of the soil that occurs continuously, is reflected in the sediment layer, and then reflected from the layer boundary with a static frequency caused by minimal vibrations under the soil surface or other natural activities. This research uses the HVSR method. The basic concept of this method is to use seismic wave recordings. The two most important parameters are obtained from the processes, namely dominant frequency (fo) and amplification factor (Ao). In principle, this parameter can describe the geological characterization [13].

The study's results obtained dominant frequency values (fo) and amplification factor (Ao) from 15 measurement points in the research area around IKN. The dominant frequency (fo) and amplification (Ao) values are obtained from the HVSR curve which is

Fig. 2. The instrument setting at microtremor measurement points.

used to calculate the seismic vulnerability index (Kg) [5]. HVSR curves obtained from processing using GEOPSY Software. The analysis is based on reliable HVSR and HVSR curve criteria with clear peaks [7]. Based on the HVSR curve analysis, 15 measurement points were obtained, which resulted in a reliable HVSR curve.

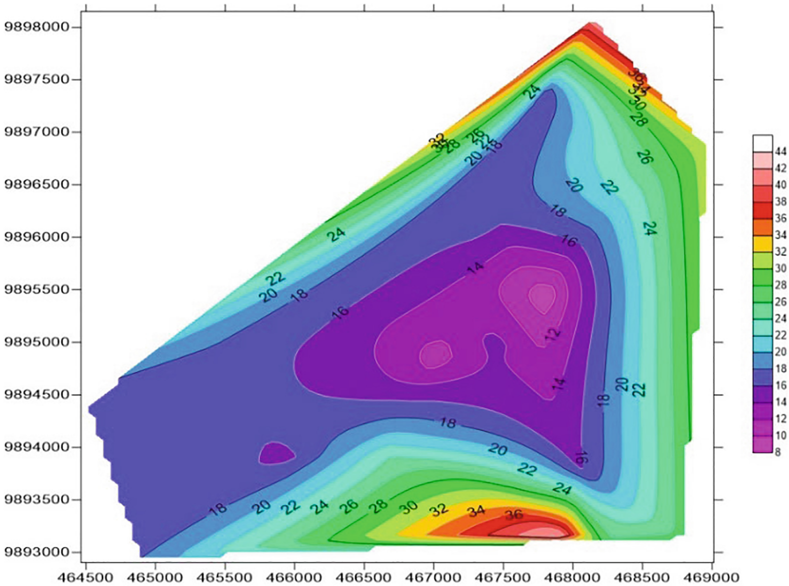

Fig. 3. Ground natural frequency (fo) distribution of the research area.

Contour map of dominant frequency values (f_0) obtained from the HVSR method shown on the Fig. 3. The dominant frequency values can be used as a planning construction reference because this parameter represents the subsurface conditions of the study area [13, 15]. Building structures that have a dominant frequency equal to the natural frequency of the soil can cause resonance phenomena. This resonance can increase the vibration amplitude which causes damage to the building above it when a vibration occurs, such as an earthquake [16]. The distribution of dominant frequency values obtained are mostly in the ranges values 8 Hz to 36 Hz. The purple color indicates the low dominant frequency distribution in the middle part of the research area. Whereas, green and red colors on the edge contour map indicate the distribution of moderate to high dominant frequency values. The range of frequency values obtained in the study area indicates that this area is composed of old sedimentary rocks and is relatively dense [17].

Microtremor measurements in this study resulted in a map of the distribution of amplification shown in Fig. 4. If the soil amplification is high, the impedance contrast between the surface and subsurface layers is also high [11]. Thus, the gain factor value is also high. Amplification occurs when seismic waves propagate from one medium to another which is softer. From the measurement results, the distribution of amplification values ranges from 3 to 6.8 as shown in Table 1. The amplification factor is generally classified into several levels. An amplification value of less than 3 is categorized as low amplification. [13]. The value range from 3 to 6 is categorized as moderate amplification. Meanwhile, values ranging from 6 to 9 and more than 9 are categorized as high and very

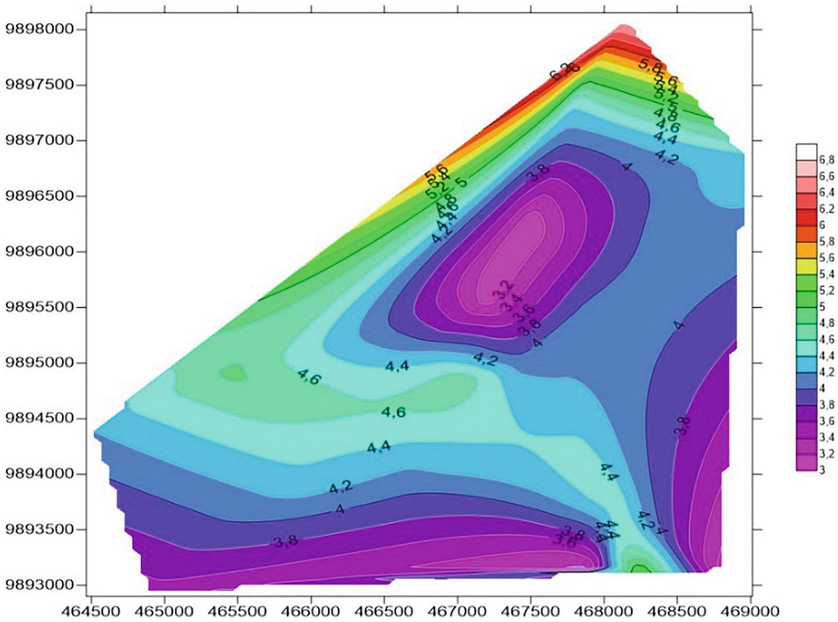

Fig. 4. The amplification values Ao) distribution of the research area.

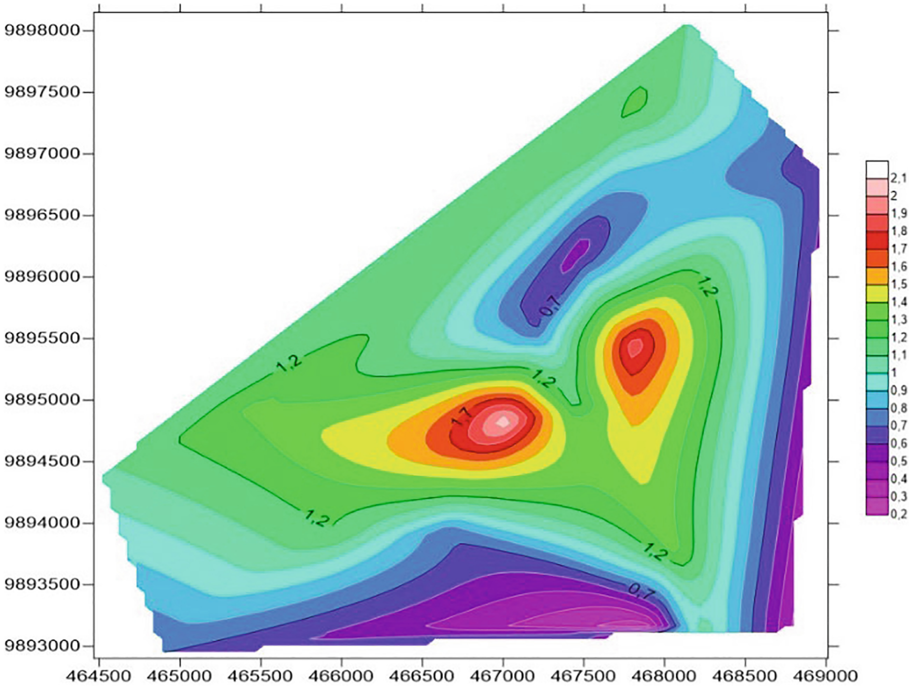

Fig. 5. Seismic vulnerability index (Kg) distribution of the research area.

high vulnerability amplification. Based on these results, the research area around IKN can be classified as a medium application.

The distribution values of the seismic vulnerability index shown in Fig. 5 describe the damage to soil and buildings in the event of a significant vibration, such as an earthquake. The values of the seismic vulnerability index at a measurement point are determined from the amplification values and dominant frequency values. A contour map of the seismic vulnerability index is made. The distribution of the seismic vulnerability index ranges from 0.2 to 2.1 which is shown by purple to red color. The purple color represents a lower vulnerability index, while red indicates a higher value. The higher the vulnerability index indicates the thicker the sediment layer. Both values indicate the vulnerability of the soil to deform due to earthquakes. Overall, the results of microzonation measurements in the IKN area can be seen on Table 1.

Table 1. Natural frequency, Amplitude, Seismic vulnerability index

Point	F0	A0	Kg
1	18.01	3.499	0.679
2	16.4	4.2	1.075
3	15.6	4.32	1.196
4	17.91	4.862	1.319
5	23.699	4.08	0.702
6	10.923	4.8	2.1
7	13.79	3.1	0.69
8	43.02	3.14	0.229
9	15.78	4.6	1.34
10	14.7	4.1	1.14
11	8.628	4.028	1.88
12	16.75	2.977	0.529
13	16.58	4.53	1.239
14	43.15	6.89	1.1
15	27.35	3.05	0.34
16	26.35	5.33	1.078
17	32.21	4.35	0.587

4 Conclusion

In this research, the distribution of dominant frequency values (f_0) ranges from 8 Hz to 36 Hz, and the distribution of amplification values (A_0) ranges from 3 to 6.8 categorized as medium amplification. Based on the calculation results, the seismic vulnerability index (K_g) ranges from 0.2 to 2.1, the higher value of K_g indicates a thick layer of sediment which means the soil conditions in the area are more vulnerable to earthquakes.

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