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Analysis of Resonance Characteristics of Multi-storey Buildings Based on Microtremor Measurements

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ABSTRACT

The diverse functions of buildings today require designs that minimize potential damage, particularly from natural disasters. Earthquakes are one of the natural disasters that pose a significant threat to buildings. For example, the earthquake that occurred in Yogyakarta in 2023 caused damage to various building facilities. This study aims to identify the vulnerability level of buildings using microtremor data to obtain the natural frequency value of the building (fb), building resonance index (R), and building vulnerability index (Kb). This research has been carried out in multi-storey buildings by measuring natural frequencies on the building and its basic land. The recorded vibration data were analyzed with the H / V technique to get its natural frequency value. The measurement results of building floor vibrations using the GPL-6A3P accelerometer show that the natural frequency

KEY WORDS: *natural frequency, accelerometer, and microtremor*

1.0 INTRODUCTION

All buildings have a natural frequency of oscillation or resonance frequency. While specific building geometries and materials control the resonance of a building, resonance frequency is largely a factor of building height. For example, taller, more flexible, buildings are susceptible to the smaller, low frequency oscillations of distant earthquakes, while shorter and stiffer buildings are more susceptible to the larger, high frequency shaking of nearby earthquakes. When seismic waves shake the ground beneath a building at its resonance frequency, the structure will begin to sway back and forth and the structural integrity of the building may become compromised

1.1 BACKGROUND

Building resonance refers to the phenomenon where a building vibrates or oscillates with greater amplitude when the frequency of external vibrations (such as earthquakes) matches the building's natural frequency. When the earthquake frequency matches the building's resonant frequency, the building will experience stronger vibrations and potentially more severe damage.

- Natural Frequency of Buildings:

Every building has a natural frequency (or resonance) which is the number of seconds it takes for the building to vibrate back and forth naturally.

- Resonance and Seismic Waves:

If the period of ground motion (seismic waves) matches the natural resonance of a building, the building will experience the greatest oscillations and potentially the greatest damage.

- BOSS Model:

The BOSS (Building Oscillating Structure Simulator) model is used to show how buildings of different heights respond to seismic waves.

- Vulnerability Analysis:

The application of the microtremor method in building vulnerability analysis can identify the natural frequencies of the ground and building to predict the potential for resonance during an earthquake.

- Resonance Examples:

Resonance can also occur in other objects, such as a tuning fork that vibrates with a greater amplitude when its vibration frequency matches the resonance box.

- Importance of Resonance:

Resonance plays an important role in everyday life, for example in capturing electromagnetic waves on radios or cell phones. Implications in Daily Life

- Structural Strength:

Understanding building resonance is essential in building planning and construction to ensure structural stability and strength.

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2.0 RESEARCH METHODOLOGY

In planning earthquake-resistant buildings, it is necessary to pay attention to the quality of a building, one of which is knowing the value of its natural frequency, where the building will experience severe damage if the natural frequency of a building and the earthquake frequency have the same or close values, so that resonance will occur. One of the efforts in planning earthquake-resistant buildings is to examine the natural frequency of the building and the building's base soil, by measuring microtremors. In addition, the maximum ground acceleration PGA (Peak Ground Acceleration) needs to be considered so that the building can withstand the acceleration of its base soil according to the design required in SNI-1726-2002 in planning earthquake-resistant buildings.

2.1 RESONANCE DEMONSTRATION DEVICE OF MULTI-STOREY BUILDINGS

High-rise building resonance demonstration devices typically involve a model structure, such as a skyscraper, and a vibration system to induce resonance. The system can use mechanical vibrations, such as actuators, or electromagnetic vibrations to vibrate the model. When the vibration frequency matches the building's natural resonance frequency, the model will begin to vibrate with a larger amplitude, demonstrating the resonance effect. Here are some key points related to the high-rise building resonance demonstration tool:

- Building Model:

The model can be made of various materials, such as wood, metal, or plastic, and its design reflects the structure of a real building. The shape and size of the model affect its resonant frequency.

- Vibration System:

This system can be a mechanical drive that produces vibrations, or an electromagnetic system that produces vibrations through a magnetic field. The vibration frequency can be adjusted to identify the resonant frequency.

- Sensor:

Sensors can be installed on the building model to measure vibrations and amplitudes. These sensors can show how much vibration occurs when the vibration frequency approaches the resonant frequency.

- Analysis:

The demonstration tool can be used to test the stability of structures, the effects of resonant frequencies, and their impact on buildings.

- Application:

This tool can be used in education to explain the concept of resonance, and also to test the design of building structures in real conditions.

Application examples:

- BOSS Model Lite:

A demonstration tool used to explain how buildings can sway when the seismic vibration frequency matches the natural resonant frequency of the building.

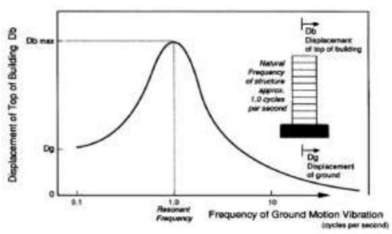
- Building model with vibration system:

The model can vibrate when the vibration frequency of the vibration system approaches the resonant frequency, demonstrating the resonance effect.

With this demonstration tool, it can be seen how resonance can affect the stability of a building, and the importance of understanding resonant frequencies for designing safe buildings, especially during earthquakes.

2.2 NATURAL FREQUENCY

Every object has a natural frequency that depends on its composition, size and shape. If the natural frequency of an object is the same as the frequency of another sound source, then resonance or wave amplitude amplification will occur, and the object is said to be resonant to the frequency of the sound source (Sears and Zemansky, 1994). If the frequency of the building is the same as the frequency of the earthquake that reaches the surface, then resonance and vibration interference will occur, increasing the intensity of damage caused by the earthquake. Based on this, the construction of buildings must consider the possibility of vibration resonance (Subardjo, 2008). This is the same as the theoretical principle used in a damped system driven by an external force that changes sinusoidally with time, the system oscillates according to the forced frequency and amplitude that depends on the frequency of the forced force. If the frequency of the forced force (earthquake frequency) is the same as or close to the natural frequency of the system (the natural frequency of the building), then the system will oscillate with an amplitude much greater than the amplitude of the forced force, this phenomenon is called resonance (Tipler, 1991). When a building is shaken by an earthquake, the frequency of ground vibrations and earthquakes will propagate simultaneously. Building response is highly dependent on natural frequency and earthquake frequency. For example, a 10-story building with a natural frequency of 1 Hertz will be affected by ground vibrations with the same frequency. However, the effect will be smaller if the frequency of the ground vibration has a greater or lesser value



Gambar 1. Diagram respon bangunan 10 lantai (Coburn dan Spence, 2002)

Building Response to Ground Vibrations According to UN-Habitat (2006), during an earthquake, the building foundation and the ground of the building

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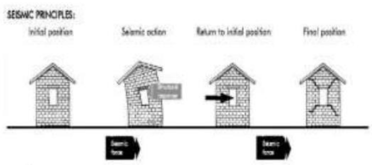
move following the seismic force (earthquake force). Before the earthquake, all building elements will be in their initial positions. When an earthquake occurs, the ground of the building and the first floor of the building will move following the direction of the seismic force. For example, when an earthquake occurs, the ground moves to the right, then the building will move in the opposite direction to the direction of the ground movement. And after the earthquake occurs, some building elements that have weak construction will be damaged because the building has low resistance and energy absorption.



Gambar 2. Respon bangunan saat terjadi gempa (UN-Habitat, 2006)

According to Coburn and Spence (2002), the main cause of damage to buildings is vibrations in the building's foundation soil. When a building is moved by an inertial force acting on the building, the building's vibration acceleration will increase. The factor that greatly determines the dynamic response of a building to vibrations is the building's natural frequency.

2.3 MICROTREMOR

Microtremor is a ground vibration that generally has a continuous nature, has a small magnitude, and is stationary. Microtremor can be a vibration caused by human activity or other activities, such as vibrations caused by people walking, vibrations from vehicles, vibrations from factory machines, wind vibrations, sea waves, or other natural vibrations. Microtremor can be used in the design of earthquake-resistant buildings, namely by knowing the natural period of the local soil to avoid resonance. Microtremor can also be used to determine the type of soil based on its hardness level (Subardjo, 2008), where the smaller the dominant period of the soil, the greater the hardness level or soil that has a larger dominant period is softer or softer in nature.

Based on the research results of Hariyadi (2009) to obtain the relationship between building configuration and building resistance and soil bearing capacity so that it can be used as a guideline in building residential houses, soil and building resistance analysis was carried out by measuring the natural frequency of the base soil and its buildings.

The measurement results show that residential houses at the research location can be divided into 3 categories, namely: safe, vulnerable, and dangerous. A residential house is said to be safe if the building has a higher natural frequency compared to the natural frequency of the base soil. A residential house is said to be vulnerable if the building has a natural frequency equal to the natural frequency of the base soil. And dangerous if the building has a natural frequency lower than the natural frequency of the base soil. In addition, the natural frequency of the base soil of the building can also be compared for its suitability with the natural frequency permitted in the earthquake resistance planning standards for buildings (SNI1726-2002).

2.4 FLOOR SPECTRAL RATIO

The FSR (Floor Spectral Ratio) method aims to determine the natural frequency value of the building and the resonance index value of the building to describe the characteristics of the building against earthquakes based on the transfer function of the building spectrum and soil spectrum. The use of this method utilizes natural waves that occur from buildings to obtain their natural frequencies.

2.5 HORIZONTAL TO VERTICAL SPECTRAL RATIO

HVSR (Horizontal to Vertical Spectral Ratio) is a method developed by Yutaka Nakamura, where this method is one of the simplest and most effective methods in estimating the characteristics of the dynamics of the soil surface layer through natural frequency and amplification based on microtremor data. This method was developed based on his experience in research on the propagation of shear waves due to earthquake events by comparing the results of the horizontal component spectrum to the vertical component of the microtremor data (Nakamura, et al., 2000). Meanwhile, to determine the vulnerability index, according to Nakamura, it can be estimated using the drift angle. This is related to the acceleration of the input earthquake and the displacement of each floor. This parameter is estimated from the frequency and amplitude on each floor obtained from the transfer function of the structure (Ayi & Bahri, 2012). Knowing the magnitude of the natural frequency value of the building against the natural frequency of the soil is one way that can be done to estimate the possibility of damage to buildings due to earthquakes. If the frequency of the soil around the building is smaller than the frequency of the building, the building is declared safe from the threat of damage due to earthquakes and if the frequency of the building is smaller than the frequency of the soil, the building is declared unsafe from the threat of damage from earthquakes (Gosar, 2010).

3.0 DISCUSSION

The methods used in microtremor analysis are the Floor Spectral Ratio (FSR) method for recording microtremors in buildings and the Horizontal to Vertical Spectral Ratio (HVSR) method for recording microtremors on the ground (Aini, et al., 2012). The parameters used to explain the level of building vulnerability are the building's natural frequency value (fb), the building resonance index value (R) and the building vulnerability index value (Kb). To validate the results of microtremor measurements, a building vibration period analysis was carried out using SAP2000 building analysis software. If the results obtained from the two analyzes are almost the same, then the results of the work can be said to be validated

The natural frequency value of the building is determined from the spectrum analysis of each floor of the building against the ground below. In determining the natural frequency value of the building based on FSR analysis, the following equation is used (Prakorsa, 2014):

$$f_b\,(FSR) = \frac{f_b NS}{f_t NS} \quad (1)$$

$$f_b\,(FSR) = \frac{f_b EW}{f_t EW} \quad (2)$$

where fb (FSR) is the natural frequency of the building based on the FSR method, fb and ft are the building and ground frequencies obtained from the FFT spectrum processing, NS and EW are the directions of the horizontal components.

Resonance occurs when the building frequency and the ground frequency have relatively the same value. The magnitude of the resonance index value provides an overview of the possibility of a building experiencing resonance during an earthquake (Sarkowi, 2022). The building resonance index value (R) for each component (NS and EW) can be determined based on the following equation:

$$R = \frac{f_b - f_t}{f_t} \times 100\% \quad (3)$$

where R is the resonance index value, fb is the natural frequency of the building based on the FSR method and ft is the natural frequency of the soil based on the HVSR method.

According to Gosar (2010), the level of resonance vulnerability is classified into three criteria, namely if the resonance value is greater than 25% it is classified as low, if the resonance value is between 15 - 25% it is classified as medium and if the resonance value is less than 15% it is classified as high. The building vulnerability index can be estimated from the structural deformation associated with seismic vibrations from the soil and the dynamic characteristics of the surface layer and structure (Nakamura, 2000).

In a study conducted by Sato (2008), regarding changes in dynamic characteristics using microtremors, the equation used to determine the building vulnerability index value is as follows:

$$K_b = \frac{A}{(2\pi f_b)^2} \times \frac{10000}{H} \quad (4)$$

With Kb is the value of the building vulnerability index, A is the amplification, fb is the building frequency, H is the height of the building and 10,000 is the noise effect. Generally, estimating the vulnerability of a building to collapse at a vulnerability index value above 100 m/s2 – 200 m/s2. So if the building vulnerability index value is below 100 m/s2 the building is safe from the threat of damage (Hadianfard, 2016).

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