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Development of Vibration Detection Prototype Using MPU6050 For Building Durability Evaluation

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ABSTRACT

Vibration does not only come from tectonic and volcanic activities, there are also artificial vibrations produced by humans such as construction, transportation, and other industrial activities. Impacts that can be caused by vibration if it occurs consistently such as small cracks. Because every year there is an increase in mobility, it has an impact on infrastructure and industrial development. Especially in high-rise buildings such as office centers where there are many occupants. Vibration can interfere with comfort and health and can even damage the structure of the building has been regulated in ISO 2361: 1997 and ISO 10137: 2007 which regulates related to comfort response and vibration evaluation from human activities. This research aims to develop a prototype that can be used as a measuring instrument to detect vibration so that it can provide information on vibrations received by buildings as one of disaster mitigation. This prototype uses MPU6050, SW-420, and Buzzer sensors and ESP8266 as a microcontroller, the data will be sent to Blynk as data storage and data viewer using Telegram so that people get notification of the amount of vibration that occurs. Testing the prototype by utilizing the massage gun vibration source with the object of a high-rise building mockup, data will be taken on each floor for 15 minutes, and get measurement data on the horizontal axis (*x*-axis *and y*-axis). The results of this study found that the vibration of 2100 - 2700 RPM captured acceleration with a range of 0.007 - 0.03 m/s^2 still in a small range to be able to demolish the building. The recorded frequency range of 10 - 26 Hz is included in the vibration caused by building occupants with a vibration coefficient of R = 8, namely the area is densely populated and the intensity of activity is high so that it can cause vibration and can be felt by other occupants. So, it can be concluded that the vibration simulation in the developed prototype can be used as a measuring tool and become a disaster mitigation system in high-rise buildings obtaining an average relative error of 6.28% with tool accuracy of 93.72%.

Keywords: Vibration Detector, Building Vibration, IoT, Accelerometer, Comfort Response

I. INTRODUCTION

Indonesia has a high level of seismic activity, this is because the Indonesian region is a meeting of four active tectonic plates including the Eurasian, Indo-Australian, Pacific and Philippine tectonic plates [1]. As a result, plate shifts will occur which will cause vibrations usually called seismic waves [2], vibrations that reach the earth's surface can damage buildings and cause other disasters. Vibrations do not only come from plate shifts, but vibrations can be generated from human activities [3] such as construction, transportation and industrial activities that can have a negative impact on the comfort of life indirectly.

Every year the population of Indonesia increases and results in progressive development. If there is an increase in activity to trigger vibration in the surrounding environment including busy road traffic, railroad tracks, industrial activities and building activities [4]. Excessive and prolonged vibration will have an impact on physical damage to buildings [5], so that mitigation measures are needed to prevent fatal damage due to vibration and the need for regulations and technical standards regarding vibration [6].

Tall buildings need to have a monitoring system that can be used as an alternative in disaster mitigation so as to minimize the number of victims in the event of a building collapse due to strong vibrations. The design of building structures, especially tall buildings, needs to take into account vibrations or shocks that can damage building structures [7]. To find out the resistance of the building, it is necessary to check the natural frequency and maximum ground acceleration or PGA (Peak Ground Acceleration) because heavy damage will occur if the natural frequency of the building and the vibration frequency have the same or close value and cause resonance [8].

PGA estimation calculations are used to determine the design of building construction as well as to improve regional spatial planning in earthquake-prone areas. Through this calculation, it can determine the potential vibration that can cause damage and the ability of the structure to withstand damage [9]. One of the tools used to measure the PGA value of the soil is the accelerograph, which is an instrument that can record ground vibrations, generally placed in areas that have vibration potential [10].

Based on previous research, the development of earthquake detection sensors and information based on the Internet of Things (IoT) is relatively cheap and accurate, the signals captured are vibration sensing utilizing MEMS accelerometers and BLE (Bluetooth Low Energy) as a communication system [11]. As for other developments that apply the Wireless Sensor Network as an earthquake warning simulation by utilizing the SW-420 sensor equipped with a Buzzer as a warning signal that emits sound, monitoring is carried out remotely and controlled via the website, if there is an earthquake then the system will provide a warning and direct the community to the gathering point of the building [12].

The building will respond to vibrations received from natural or artificial vibrations, so to find out the amount of vibration felt, an IoT-based vibration detection device is needed by utilizing the development of today's information systems, then a warning will be sent via Telegram message if a vibration is detected that is strong enough and has a high risk of damage. The sensors used are MPU-6050 as an acceleration detector, SW-420 as a vibration detector and Buzzer as a vibration information signal.

II. METHODS AND MATERIAL

A. Vibration parameters and comfort response

In this study, the data to be used is acceleration data from the MPU-6050 sensor. A literature study was conducted on standard methods, regulations and scientific articles or books related to vibration measurement parameters based on acceleration (g, gal and m/s^2) and frequency (Hz). Vibrations that occur in uilding structures are divided into several vibration criteria as in Figure 1 which is an individual response hen there is vibration [13].

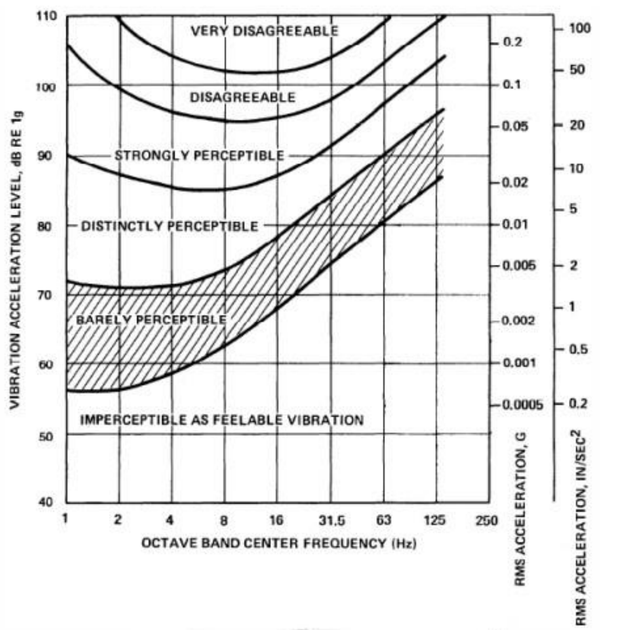

Figure 1: Approximate Sensitivity and Response of People to Feelable Vibration [13]

The vibration sensitivity threshold felt by individuals/building occupants is in the shaded part of Figure 1 with an acceleration range of 0.001 - 0.005 g, if more than that the vibration felt can be dangerous. As regulated in the International Organization for Standardization (ISO) which provides guidelines or measurement methods. ISO-2631-1-1997 describes the comfort level of individual perception of vibration as shown in Figure 2.

less than 0.315m/s^2	not uncomfortable
0.315 m/s^2 to 0.63 m/s^2	a little uncomfortable
0.5 m/s^2 to 1 m/s^2	fairly uncomfortable
0.8 m/s^2 to 1.6 m/s^2	uncomfortable
1.25 m/s^2 to 2.5 m/s^2	very uncomfortable
larger than 2 m/s^2	extremely uncomfortable

Figure 2: Comfort reaction to perceived vibration based on acceleration [14]

Vibration monitoring and evaluation of the impact of vibration on the building environment that can be used as a factor to determine the source of vibration originating from individual activities by setting acceleration and frequency parameters, see in Figure 3.

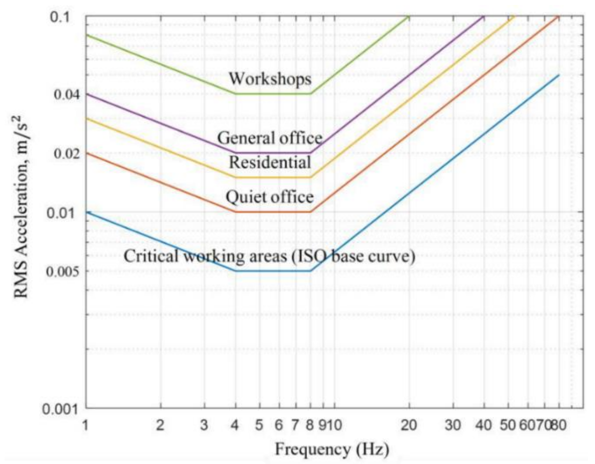

Figure 3: Vibration evaluation curves in a given environment with varying individual activity levels [15]

B. Design of detection system

This system is designed to record the acceleration value of the vibration received by the building when mechanical vibration occurs in the building, for the general hardware design is shown in Figure 4.

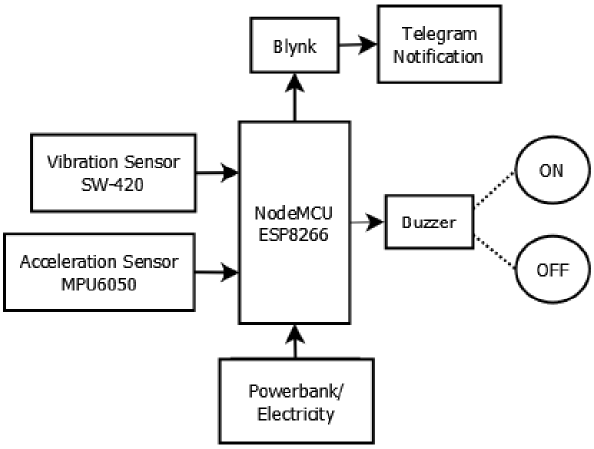

Figure 4: Block diagram of building vibration detection system

Based on Figure 4 is part of the hardware design for vibration detection that will be developed using several sensors, namely MPU6050 and SW420 because they are cost-efficient and portable.

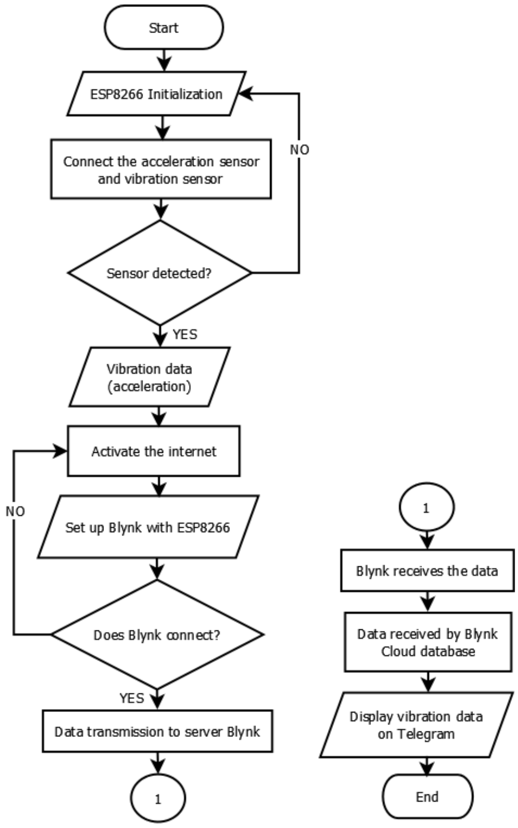

Figure 5: Flowchart of the vibration detection system

The process of designing to testing the vibration detection system is shown in Figure 5 by initiating the NodeMCU so that other sensors can receive data collection instructions and reception to the user.

Data collection is carried out using a building mock-up made of PVC foam board with a size of 12x12x12 cm for each floor and arranged as many as 4 floors as shown in Figure 6. Before taking measurements, it is necessary to pay attention to the condition of the mock-up must be in a position parallel to the floor surface, therefore it is necessary to determine the flat position of the mock-up with a waterpass because it can be an external factor in acceleration data errors.

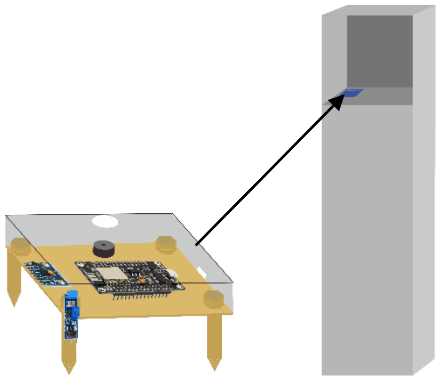

Figure 6: System development design and data capture position

Based on SESAME 2004, vibration data for each floor is taken for 15 minutes alternately. The data obtained is the acceleration against time (time domain) and will then be converted into the frequency domain by Fast Fourier Transform in LoggerPro. The acceleration value recorded by the MPU-6050 sensor has 3 measurement axes X, Y and Z, but only the X axis and Y axis are used because the Z axis is in the direction of the earth's gravitational acceleration (1g).

III. RESULTS AND DISCUSSION

A. Sensor Calibration

Each sensor used needs to be calibrated by comparing the output of the sensor and calibrator, in this study the MPU6050 sensor was calibrated with the Phyphox calibrator. It aims to match the two measuring instrument data and data fitting is carried out to determine the linearity graph of the two data.

Calibration is done using a vibration of 2400 RPM set at a distance of 10 cm from the sensor and the average acceleration value on each floor is taken, the results are shown in Figure 7.

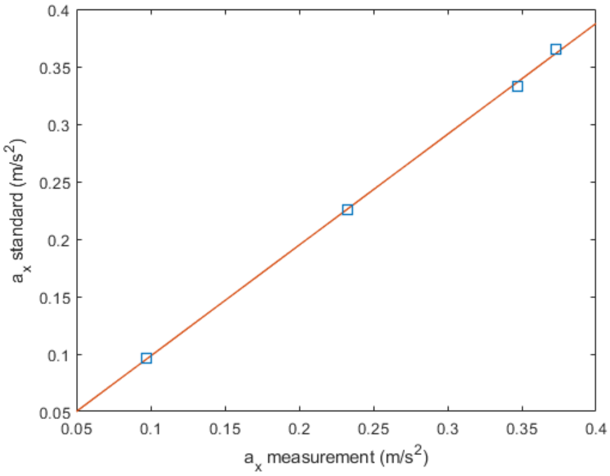

Figure 7: Calibration graph of sensor data on the *x*-axis

Determining the average value of the relative percentage error of sensor data readings with standard measuring instruments for each sensor data on each floor with equation (1).

$$\%error = \left|\frac{a_{meauserement} - a_{standard}}{a_{standard}}\right| \times 100\% \quad (1)$$

The results of fitting the calibration data for the sensor on the y-axis obtained a graph as shown in Figure 8.

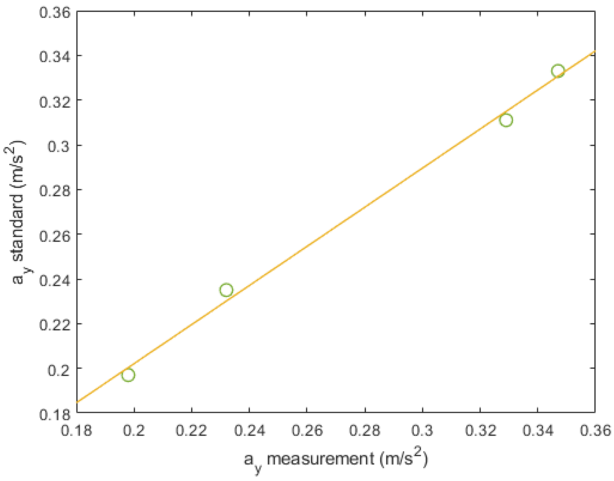

Figure 8: Calibration graph of sensor data on the *y*-axis

Based on the data obtained, the relative percentage error of each floor can be determined using equation (1) shown in Table I below.

TABLE I
Average percentage of Relative Error for each mock-up floor

Potition	Relative Error of Data	
	x	***y***
1st-floor	7,48%	5,69%
2nd-floor	4,76%	6,09%
3rd-floor	6,77%	7,01%
4th-floor	6,62%	5,81%

Overall based on Table 1 the relative percentage error of each floor is below 10%, so the data obtained is accurate and the calibrated measuring instrument can be used to make measurements.

B. Testing the Vibration Detection Device

The vibration source used in testing the tool is a massage gun type SY-720 by varying the vibration level from 2100 - 2700 RPM and rotating for each floor of the building mock-up, vibration data is taken for 15 minutes/floor, as shown in Figure 9.

Figure 9: Vibration data acquisition with massage gun

Data from measurements taken for 15 minutes per floor, then the most frequently occurring data (mode) will be taken because the data is sensitive to vibration and there are many of them, so the results of data analysis are shown in Table II.

TABLE II
Vibration measurement results for each floor and description of perceived vibrations

Position	Axis	Acceleration (g)	Freq. (Hz)	Vibration Description
1st-floor	*x*	0,017	10,20	*Distinctly perceptible*
	y	0,011	13,02	*Distinctly perceptible*
2nd-floor	*x*	0,024	12,30	*Distinctly perceptible*
	y	0,007	17,04	*Distinctly perceptible*
3rd-floor	*x*	0,028	26,53	*Strongly perceptible*
	y	0,013	26,61	*Distinctly perceptible*
4th-floor	*x*	0,016	23,87	*Distinctly perceptible*
	y	0,030	21,70	*Strongly perceptible*

For visualization of vibration data recorded by the development tool for each floor, there are differences in the peak of vibration felt, more details are shown in Figure 10.

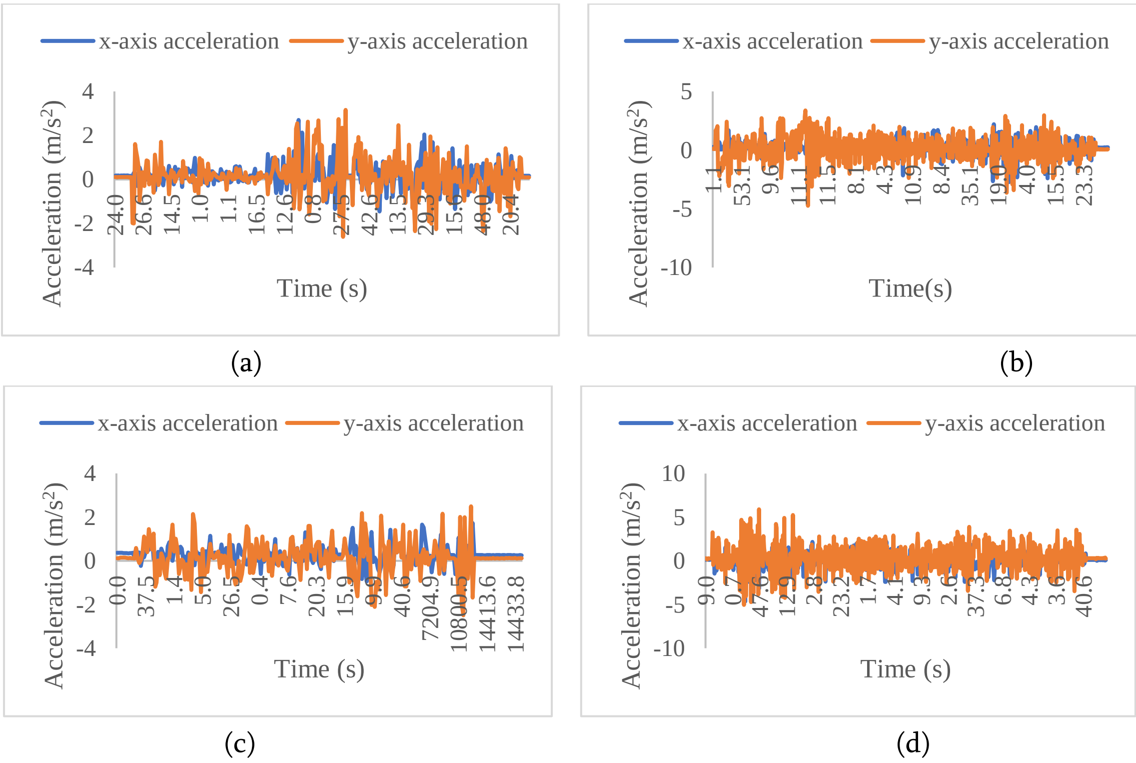

Figure 10: Graphs between acceleration in the x-axis and y-axis with time at each condition for: (a) 1st floor, (b) 2nd floor, (c) 3rd floor and (d) 4th floor

C. **Discussion**

The vibration that can be felt by the measuring instrument for each floor is different as in Figure 10, it can be seen that the vibration peak for the 3rd floor (Fig. 10c) is the lowest among the other 3 floors, whereas the highest vibration peak felt on the 4th floor (Fig. 10d), while 2nd floor (Fig. 10b) the vibration peak is in the higher negative direction which can be due to the building mock-up moving more dominantly to the left, for the 1st floor (Fig.10a) the vibration peak has a fairly high distribution evenly. Based on the high and low vibration peaks, it states that the vibration felt is quite large.

Based on Table II the vibration value of each floor can be felt clearly and slightly strong. For vibrations that can be felt or not refer to Figure 1 which illustrates the graph of vibration sensitivity levels based on known acceleration (g). Therefore, the average measurement data of acceleration on the 1st floor to the 4th floor is dominant, the vibration can be felt and is slightly strong on the 3rd floor and 4th floor.

When viewed from the direction the vibration on the 1st floor to 3rd floor has a fairly high acceleration value in the x direction compared to the y direction which has a low acceleration. Therefore, the vibration that propagates from the bottom of the mock-up to the top is dominantly moving forward (North-South direction). There is a slight difference on the 4th floor where the dominant vibration in the y direction feels strong but not dangerous, this can happen because it gets vibration propagation from the bottom and causes the highest position to be more sensitive to feeling strong enough vibrations, while for the x direction on the 4th floor, it is almost the same to feel strong enough vibrations (but the resulting propagation is not large).

This acceleration data can also be analyzed if viewed based on the level of comfort response of occupants or individuals in a building when vibrations are felt. The international policy that regulates this is ISO 2361: 1997 (see Figure 2). If you look at the average acceleration data for each floor the value is below 0.315 m/s^2 which indicates that the vibrations arising from the vibration source can be felt by people who are in the building but still feel comfortable to be able to continue activities as usual even though the surroundings feel vibrations and do not interfere with activities.

To determine the amount of vibration generated from the vibration source, the analysis determines the dominant frequency from the time domain data to the frequency domain by performing Fast Fourier Transform (FFT) analysis using LoggerPro, as shown in Table II, the frequency value is taken from the frequency with the highest peak (high amplitude).

If the frequency data obtained is reviewed based on international policies in ISO 10137: 2007 related to individual or group activities in buildings that produce vibrations due to these activities, it has several levels (see Figure 3). Based on the data in Table II, the frequency value on each floor varies with the vibration felt in the x-direction and y-direction.

On the first floor, an average acceleration of 0.014 m/s^2 and a frequency range of 10 - 13 Hz would allow the building to be used as a high-intensity workplace for many occupants. The 2nd floor section has an average acceleration of 0.015 m/s^2 and a frequency range of 12 - 17 Hz indicating the building is used as a workplace. On the 3rd floor which has an average acceleration of 0.021 m/s^2 and a recorded frequency range of 26.5 - 26.6 Hz, the frequency is large enough that this building is used as a workplace or fitness center that has a heavy load. Meanwhile, the 4th floor with an average acceleration value of 0.023 m/s^2 and a frequency range of 21.7 - 23.8 Hz indicates that this building is used as a workplace or other activities that require a lot of movement. Overall, this 4th floor building is used as a workplace either the office or fitness center and others, and has a vibration coefficient value of R = 8 seen from the level of limits on each frequency and acceleration value. So, vibration testing using massage gun vibration sources produces a large enough acceleration value on each floor, this is because, during the data collection process, the vibration source is in a position directly adjacent to the building mock-up.

Through the vibration information obtained, it can be used as disaster mitigation, because buildings need to record and fully monitor the vibrations that arise in buildings that can endanger many people, so that monitoring vibrations, especially in high-rise buildings, is needed and needs to be evaluated when a very large vibration occurs (for example: earthquake).

IV. CONCLUSION

In this study, the development of a prototype vibration detector using the MPU6050 sensor has been calibrated with Phyphox to determine the feasibility and sensitivity of the sensor to vibration, the percentage value of the relative error on each floor sequentially in the x- direction is 7.48%; 4.76%; 6.77%; 6.62% and for the y- direction is 5.69%; 6.09%; 7.01%; 5.81%, with a relative error value that is $<10\%$ indicating the measuring instrument is feasible to use. Testing the measuring instrument using a vibration source from a massage gun and a 4-story building mock-up, vibration data was taken for 15 minutes. Utilizing SW420 and Buzzer as notification of vibration.

The results of the data in the form of acceleration and frequency are explained based on ISO international policy on individual comfort response to vibration and individual activities that cause vibration, obtained the acceleration range using a massage gun which is 0.007 - 0.03 m/s^2 does not have a high risk and the building includes a workplace building (with R = 8). The prototype can detect vibrations and the building mock-up can receive vibrations that are quite noticeable but not harmful.

V. REFERENCES

[1] Verstapen, H. Th. 2014. Indonesian Landform and Plate tectovics. Indonesian Journal on Geoscience, 5(3), 197-207. http://dx.doi.org/10.17014/ijog.5.3.197-207

[2] Geurts, C., Bronkhorst, O., Moretti, D., Pruiksma, J., & Snijders, R. 2020. Characterization Of Vibration Measured in The Groningen Building Monitoring Network. EASD Procedia XI International Conference on Structural Dynamics, Athens, Greece: 23 – 26 November 2020. pp. 1147-1177. https://doi.org/10.47964/1120.9093.19232

[3] Hao, Y., Qi, H., Liu, S., Nian, V., & Zhang, Z. 2022. Study of Noise and Vibration Impact to Buildings Due to Urban Rail Transit and Mitigation Measures. Sustainability, 14(5), 3119. https://doi.org/10.3390/su14053119

[4] Purwanto, B., Zulfachmi, & Purwaka, P.B. 2022. Mechanical Vibration Measurement Based on Building Type. ECOLAB, 16(1), 31-38. http://dx.doi.org/10.20886/jklh.2022.16.1.31-38

[5] Bronkhorst, O., Moretti, D., & Geurts, C. 2021. Vibration Threshold Exceedances in The Groningen Building Vibration Monitoring Network. Frontiers in Built Enviroment. 7:703247. https://doi.org/10.3389/fbuil.2021.703247

[6] Gu, H., Liang, H., Tong, G., Liu, F., Liu, Y., Liu, X., Jia, Z., & Paul, J. 2021. Research on Vibration Mechanism and Control Technology of Building Structure Under Earthquake Action. Journal of Vibroengineering, 23(6), pp 1395-1406. https://doi.org/10.21595/jve.2021.22090

[7] Kowalska-Koczwara, A., Pachla, F., & Nering, K. 2021. Enviromental Protection Against Noise and Vibration. IOP Conference Series: Materials Science and Engineering. San Francisco, 26-30 May. Pp. 1-8.

https://doi.org/10.1088/1757-899X/1203/3/032026

[8] Alam, H., Kusuma, B. S., & Prayogi, M. A. 2020. Penggunaan Sensor Vibration Sebagai Antisipasi Gempa Bumi. Journal of Electrical Technology, 5(2), 43-52.

[9] Sungkowo, A. 2018. Perhitungan Nilai Percepatan Tanah Maksimum Berdasar Rekaman Sinyal Accelerograph di Stasiun Pengukuran UNSO Surakarta. Indonesian Journal of Applied Physics, 8(1), 43-51. http://dx.doi.org/10.13057/ijap.v8i1.14326

[10] Munoz, M., Guevara, R., Gonzalez, S., & Jimenez, J.C. 2021. Reliable Data Acquisition for Low-Cost Accelerograph Applied to Structural Health Monitoring. Journal of Applied Science, Engineering, Technology, and Education, 3(2), 181-194. https://doi.org/10.35877/454RI.asci159

[11] Jongbin, W., Junyoung, P., Jong-Woong, P., & In-Ho, K. 2020. BLESeis: Low-Cost IoT Sensor for Smart Earthquake Detection and Notification. Sensors, 20(10), 1-13. https://doi.org/10.3390/s20102963

[12] Ishomyl, M., Waluyo, Mustafa, L.D. 2020. Implementasi Wireless Sensor Network Pada Simulasi Peringatan Gempa Bumi Menggunakan Sensor SW-420. Jurnal Jaringan Telekomunikasi, 10(1), 38-44. https://doi.org/10.33795/jartel.v10i1.184

[13] Guyer, J.P. 2013. An Introduction to Vibration Control in Buildings. Continuing Education and Development, Inc. New Jersey, United States.

[14] ISO. 1997. ISO 2631-1 Mechanical Vibration and Shock Evaluation of Human Exposure to Whole-Body Vibration. International Organization for Standardization. Geneva. Switzerland.

[15] ISO. 2007. ISO 10137 Bases for Design og Structures Serviceability of Buildings and Walkways Against Vibration Second Edition. International Organization for Standardization. Geneva. Switzerland.

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