Study Characteristics of a Multipurpose Reactor Building G.A. Siwabessy using Floor Spectral Ratio

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Abstract. The G.A. Siwabessy Reactor is a vital national object of Indonesia's nuclear infrastructure. These nuclear facilities are vulnerable to earthquake shocks due to regional tectonic activity. This could have a major impact on society and the surrounding environment if a nuclear disaster occurs. To mitigate hazards, we investigate location and building characteristics through Horizontal to Vertical Spectral Ratio (HVSR) and Floor Spectral Ratio (FSR) analysis. We determine the natural or dominant frequency (f_0) and the amplification factor (A_0). We carried out data acquisition on 8 - 19 January 2023 using the Lennartz LE-3D/20s short period seismometer. The data collection time was 31 minutes with 100 Hz sampling. We analyzed the data using Geopsy software. The natural frequency range obtained for wave propagation based on the direction of the NS component is in the range 1,423 – 4,726 Hz. For wave propagation in structures with the EW component direction, the f_0 value is in the range 1,280 Hz to 9,753 Hz and the average f_0 value in this direction is 2,957 Hz. This research will be a reference in the Periodic Safety Assessment regarding the resilience of building structures due to changes in the maximum ground acceleration value as a condition for extending the operational permit for the G.A. Siwabessy reactor.

1 Background

Earthquake is a natural hazard due to tectonic activity. The earthquake occurrence cannot be predicted. As Indonesia is a geological active region, we observe large number of seismicity in Indonesia. Based on United States Geological Survey (USGS) catalog, it is estimated about 1255 earthquakes with magnitude of 4.5 – 7.5 occured westen Java and southern Sumatra Islands between 1990 – 2023 (Figure 1.1).

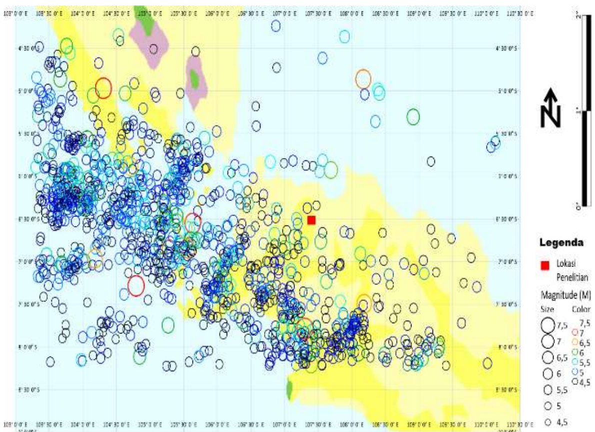


Fig. 1.1. Map of the distribution of earthquakes that have occurred around the study area (marked in red) during the period January 1990 to February 2023 based on the USGS catalog. This distribution map not only shows the epicenter of the earthquake, but also shows the magnitude of the earthquake that occurred between 4.5 to 7.5. [1]

Nuclear facilities are classified as vital facilities in each country. This vital classification is not only because of an important facility, but also has a large potential risk and can affect the national stability of a country if the facility experiences an unwanted disaster. One of the largest nuclear facility areas owned by Indonesia is the Serpong Nuclear Area which is in the Region for Science and Technology B.J. Habibie, Setu, Tangerang Selatan, Banten.

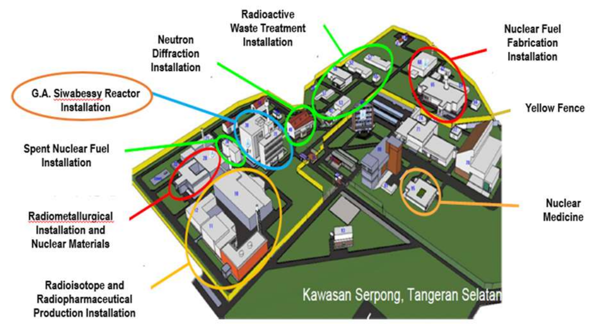


Fig. 1.2. The Serpong Nuclear Area which consists of various nuclear installations to support the main installation, namely the G.A. Siwabessy reactor with optimal thermal power of 30 MW.

Due to its location, the Serpong Nuclear facility is prone to earthquake hazards. The possibility of high magnitude earthquakes in this region is quite high and may pose a risk to the facility.

Ever since the reactor construction in the 1980s, the reactor safety document shows that the RSG-GAS core design was developed based on the core integrity in case of external disturbance of earthquakes. The cooling of the nuclear core reactor can still be carried out when an earthquake of magnitude 0.25 g strucks [2]. In 2016, (National Nuclear Energy Agency) BATAN conducted site study for new experimental reactor in the same area (~ 2 km from the RSG-GAS). The site study document shows that the maximum acceleration is estimated up to 0.57 g within 10,000 years from a megathrust earthquake [3].

The ground acceleration difference between the reactor safety analysis report (0.25 g) and the site study (0.57 g) caused the Indonesian Nuclear Regulatory Agency (BAPETEN) asked National Nuclear Energy Agency (BATAN) or now National Research and Inovation (BRIN) to report or study that the current facility is able to withstand the new ground acceleration value [4].

In an effort to determine the characteristics of the G.A. Siwabessy reactor building, we apply micotremor method. We analyze the data using Horizontal to Vertical Spectral Ratio (HVSR) and Floor Spectral Ratio (FSR). The main objective of this study is to identify the characteristics of the G.A. Siwabessy reactor building and connecting building as one reactor installation unit. We estimate the natural frequency and the amplification value of the waves that propagate through the ground around the reactor installation and that of waves propagating through in the reactor building.

2 Method

2.1 Microseismic

In determining the potential risk of earthquake hazard, there is a method by analyzing the natural vibrations of the Earth, commonly known as microtremor or microseismic. Microseismic is a vibration of the Earth. The weak vibration can be originated from the human activity, ocean waves, wind, traffic and others. Source of microtremor or miscroseismic can be divided into natural and artificial sources. Examples natural microseismic can come from rain, wind, running water, or ocean waves, while sources of artificial microseismic generally come from industrial and human activities, including the sound of machines, cars, people walking, and so on. The amplitude of the microseismic is so small that it is difficult for humans to detect it, but with the development of technology, instruments that can detect these waves are created, which are commonly called seismometers [5]. Previous studies have shown that microtremor consists of body and surface waves, although the wave motion cannot be explained in detail by theory [6].

The current microseismic method has been developed into a method for identifying the dynamic characteristics of soil and building structures. The use of this method is generally used for initial surveys in the geotechnical field. The choice of this method is not without reason, simple and cheap measurements are the advantages possessed by this method so that it is widely chosen to identify the natural frequency of the ground and the amplification of a building. Soil vibration with an amplitude displacement value of around 0.1-1 µm and an amplitude velocity of 0.001-0.01 cm/s. The recording results are expected to come from ambient noise which can provide an overview of the spectral response of the soil from a study area. In theory, if a wave propagates through hard rock then the Horizontal (H) and Vertical (V) component values will tend to show nearly the same value, whereas if the wave propagates through an area with soft rock, the H component results will experience amplification.

2.2 Horizontal to Vertical Spectral Ratio (HVSR)

A number of empirical studies have been conducted to demonstrate the reliability of the HVSR method as a transfer function. The newest method was proposed by Nakamura [7]. This method is used to identify the dominant resonance frequency of the sediment layers using the horizontal to vertical wave spectral Fourier transform ratio of the microtremor data. By comparing the fundamental frequency obtained from the microtremor H/V spectral ratio with the function received from the seismic log, the researchers concluded that the H/V microtremor spectral ratio provides a reliable estimate of sediment frequency [8].

The HVSR method (or H/V, or the Nakamura Method) is used to analyze the dynamic characteristics of the soil layers. Investigations that were previously carried out using drilling have become more effective, fast, and inexpensive using microseismic observations with HVSR analysis [7]. With these advantages this method is used in the geotechnical field to identify soil before carrying out further research through drilling, so that it becomes more effective and efficient.

The analysis of HVSR is to compare the wave component that propagates horizontally (H), which the seismic wave propagates in the North-South and East-West components, with the component that propagates vertically (V or Z) (H/V). The analyzed waves can originate from microseismic waves to estimate the resonance frequency and soil amplification conditioned from the dynamics of the surface layer. HVSR analysis mathematical equation [9].

$$HVSR = \frac{\sqrt{[S\ tanah\ (f)_E]^2 + [S\ tanah\ (f)_N]^2}}{[S\ tanah\ (f)_Z]} \qquad (3.1)$$

where :

S : Spectra
f : Frequency value
E & N : Horizontal wave direction
Z : Vertical wave direction

Based on the above, equations several soil parameters are obtained from the results of processed data. Table 2.2 shows the physical soil parameters that can be derived from the HVSR measurement.

Table 2.1. Classification of amplification factor values [10]

Zone	Classification	Amplification Factor (A_0)
1	Low	A < 3
2	Currently	3 ≤ A ≤ 6
3	High	6 ≤ A < 9
4	Very High	> 9

Table 2.2. Soil classification is based on the value of the predominant frequency of microtremor, and according to Kanai and Omote – Nakajima (modification [11])

Soil classification		Freq (Hz)	Kanai Classification	Charac
Type/ Kanai	Omete - Nakajima			
I	A	6,667 – 20	Older tertiary rocks. Consists of Hard sandy gravel, etc	Hard
II		10 – 4	Alluvial rock with a thickness of 5m, consisting of sandy gravel, dandy hard clay, loam etc	
III	B	2,5 – 4	Alluvial rock, >5m thick. Consists of sandy-gravel, sandy hard clay, loam, etc	Soft
IV	C	<2,5	Alluvial rock formed from delta sedimentation, top soil, silt, etc. with a depth of 30 m or more	Very Soft

2.3 Floor Spectral Ratio (FSR)

Earthquakes are a dynamic event of the earth and generally occur due to the movement of tectonic plates that touch or collide with each other. Earthquakes are a source of vibrations that can interact massively with building structures. The source of vibrations originating from earthquakes is generally complex (consisting of various frequencies from each earthquake events), but will have a frequency which generally has a dominant value. The vibration frequency will interact with the structure's dynamic characteristics, which is closely related to its response to vibration. This is because the dominant frequency can resonate with buildings that have the same natural frequency.

The use of HVSR is not recommended when determining transfer function parameters in buildings, this is because only in a few cases it gets good results. This inaccuracy is because it cannot be assumed that the horizontal and vertical spectra have a fixed (unchanging) value at ground level, so there is no reason to use them in the assessment of building structures. If this is still implemented in buildings, it will likely be very dangerous in cases of very strong soil amplification, because the analysis results are not close to the actual situation. In this case, the HVSR may give an incorrect assessment or building response because it is identified as a spurious transfer function parameter [12] [13].

Many researchers also study the relationship between earthquake damage and soil properties. The aspects studied are the amplitude and frequency of earthquakes [14] [15], the dynamic nature of buildings during and after earthquakes that cause damage [16]. In addition, energy is transferred back to the ground from the vibrating structure resulting in potential damage to the building due to ground structure resonance [17].

All subsequent analyzes were carried out using the (EW and NS) spectra of ambient noise inside the building, and the spectral ratios of the upper and lower floors (free-field near the building) were analyzed for both components [12] [18]. The method proposed by Gosar [18] is called Floor Spectral Ratio (FSR) and until now is the standard method in determining the parameters of the building transfer function [12].

Explanation of the use of the FSR method has been carried out in research on buildings that have a height of 10 floors and have a natural frequency of 1 Hz which will respond to vibrations with the same frequency of 1 Hz. In the concept of physics, if an object has the same frequency, and if one of them (object A) is vibrated, then the other object (object B) will resonate with the vibration marked by the vibration, object B due to the vibration of object A. This event is commonly called a resonance event. However, if the natural frequency of the building is lower or higher than 1 Hz, the response that will occur is likely to be smaller because the resonance event does not occur [19].

An example of building resistance investigation using geophysical method was carried out at the Tower of Pisa. In this study, Nakamura recorded each height level of the Pisa Tower, and divided it into four sides of the building according to the cardinal directions to obtain detailed characteristics of the Pisa Tower building structure [7]. Subsequent research, continuing from previous activities, namely by knowing the vulnerability of the Colloseum Monument building structure [6] to obtain more detailed parameters related to its curiosity in the characteristics of a building in this microseismic method such as the horizontal deviation of the structure and the deviation between levels using the predominant frequency of the structure and the acceleration of the structure.

The purpose of this study was to determine the characteristics of the soil in the G.A. Siwabessy reactor installation, and buildings (reactor building and staircase building) in the form of natural frequency values of the land and buildings, and the soil amplification values in the reactor site area. This information will provide an overview of the direction of movement of the structure using the FSR method, as well as the ability of the soil (reactor site) to support the building so that it remains standing firmly based on the processing results of the HVSR method in the KNS area. Based on these results, we hope to determine the response characteristics of the structure. Furthermore, in its development, information on the dynamic characteristics of building structures is used as a quantitative parameter to determine the resistance of building structures to earthquake disaster mitigation.

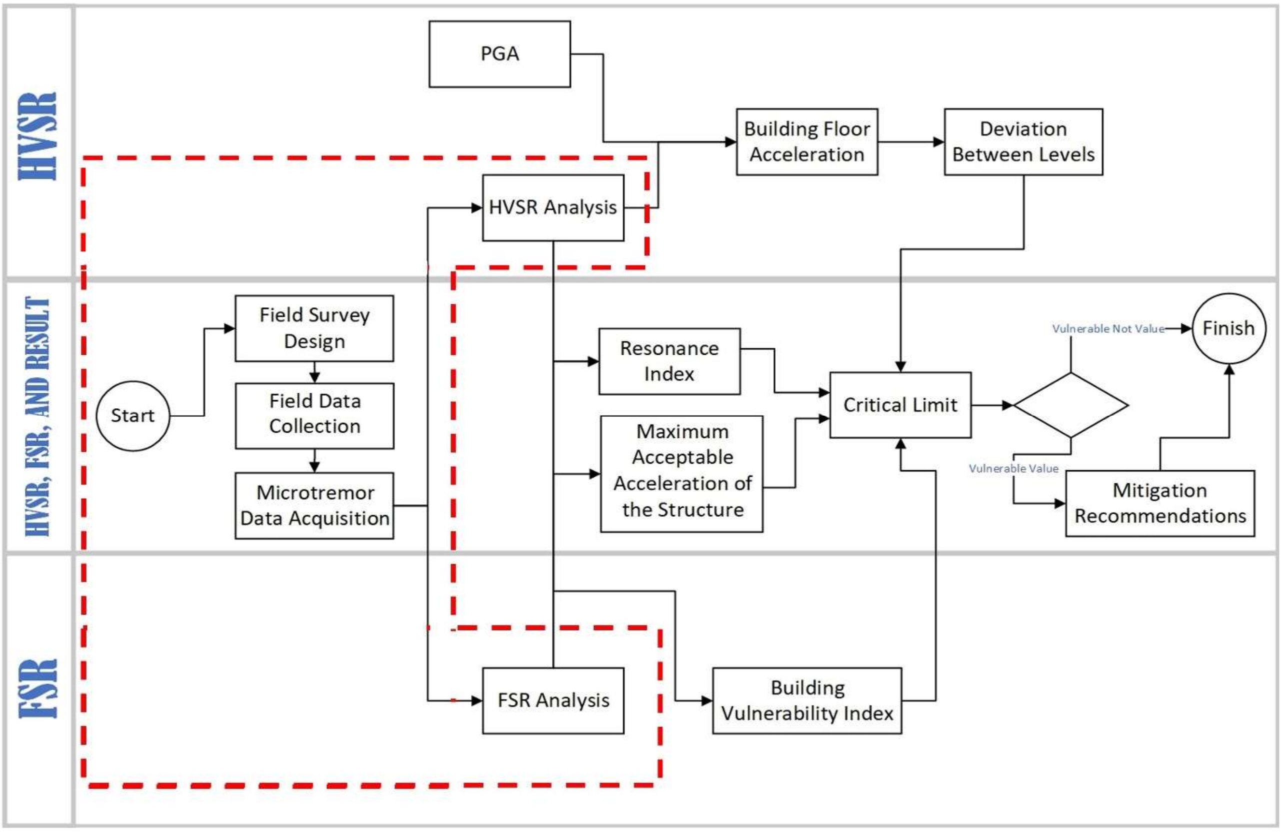


Fig. 2.1. Flow diagram of research activities in an effort to determine the characteristics of the G.A. Siwabessy reactor building. in an effort to deal with the potential value of maximum ground acceleration in the reactor site area. The dotted box describes the position of this article in the existing body of research.

In Fig. 2.1. explains the steps taken including the analysis of measurement results in an effort to determine the characteristics of the G.A. Siwabessy reactor building., while the current research position has only reached HVSR analysis and FSR analysis in an effort to obtain f_0 and A_0 parameters from below the surface of the G.A. Siwabessy reactor site. and the G.A. Siwabessy reactor building. at every floor level and side of the building.

3 Data Acquisition

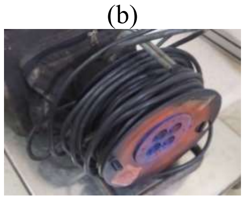
3.1 Materials and tools in microseismic data acquisition

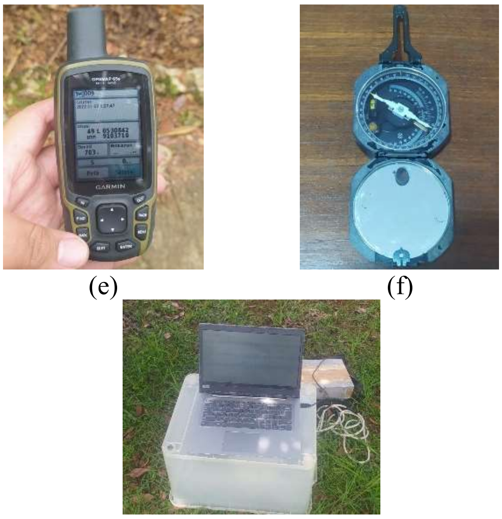
In data acquisition, we used seismometer (Figure 3.1 (a)) from Lennartz Electronic LE-3D/20s. The seismometer has three components so that it can detect vibrations from three directions, namely two horizontals (NS, EW) and one vertical direction (Z). We carried out the data acquisition on January 8, 2023 to January 19, 2023. We recorded the microtremor/microseismic for about 31 minutes and sampled at 100 Hz.


(a)


(b)


(c)


(d)



(e) (f) (g)

Figure 3.1. Equipment used for this study (a) seismometer. (b) data loggers. (c) infrared meters. (d) cable roll. (e) handy GPS. (f) compass. (g) containers (used when collecting recorded data outside the building), laptops, as well as software for recording data and subsequent data processing.

The microtremor data measured by the seismometer is a continuous analog signal, while data processing needs to be done digitally. To meet this need, an instrument that can convert analog signals to digital (Analog to Digital Converter/ADC) is needed, namely a data logger (Figure 3.1(b)). Data logger instruments can record, display data in real-time, and store data in digital storage. The data logger used in this research is DATAQ Instruments type DI-710-ULS. The specifications of these tools are as follows:

Table 3.1. Specifications of seismometers and data loggers used in data acquisition.

Informations	Data Loggers	Seismometer
Power Supply	9-36 V DC, maks 2 Watt	10….16 V DC
Power Consumption @12V DC	-	50 mA
Dimensions and Weight	13,8 x 10,48 x 3,81 cm (397 gram)	(165x195 mm) dan 6.5 Kg
Operational Temperature	0… +70°C	-15…..+60 ^{0}C
Number of Channel	16	-
Maximum Output Voltage	30 V DC atau peak AC	± 10 V
Channel	8 bit bi-directional	-
Output Current	-2,5 mA (max source) dan 2,5 mA (max sink)	-
Type	Succesive Approximation	-
Resolution	14-bit	-
Time Conversion	69 µs	-

Sensitivity	-	1000 V/(m/s)
Damping	-	0.707 critical
Material	-	Aluminum, splash-resistant, height-adjustable legs, nivo bubble.
Natural Frequency	-	0.05 Hz
Top Frequency	-	~50 Hz
RMS Noise @ 1Hz	-	<2 nm/s
Dynamic Range	-	136 dB
Poles	-	3 poles: –0,222/+0,235j –0,222/–0,235j –0,230/±0,000j
Zeroes	-	0,000/0,000j 0,000/0,000j 0,000/0,000j

3.2 Data collection

Data collection for this research record is divided into two parts/section. One point is outside the nuclear facility building as a reference location, which is used to estimate the soil condition. The reference is approximately 124 meters from the reactor building (point C in Figure 3.2) [20].

Point C is one of the microseismic measurement points carried out to determine the underground condition of the KNS area. In determining the location of the HVSR measurement point to data processing, it is carried out in accordance with existing guidelines. The selection of point C as a reference assumption that can describe the subsurface conditions of the G.A. Siwabessy reactor is point C having the closest distance to the reactor when compared to other measurement points that have gone through reliability tests and clear peak tests according to existing guidelines.

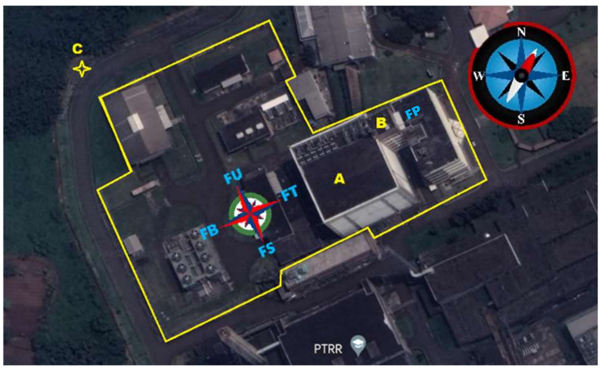


Fig. 3.2. The location for taking seismic data recordings at the G.A. Siwabessy reactor installation. Reactor installation G.A. Siwabessy is marked with a yellow line area, while the information for point A is the reactor building G.A. Siwabessy (FU, FS, FB, and FT). Point B is a stair building (FP) connecting the office building and the reactor building as well as a place for several supporting systems for the

reactor. Point C is the point for recording seismic data outside the reactor building, point C is also named point HK9 in HVSR measurements in the Serpong Nuclear Area [20].

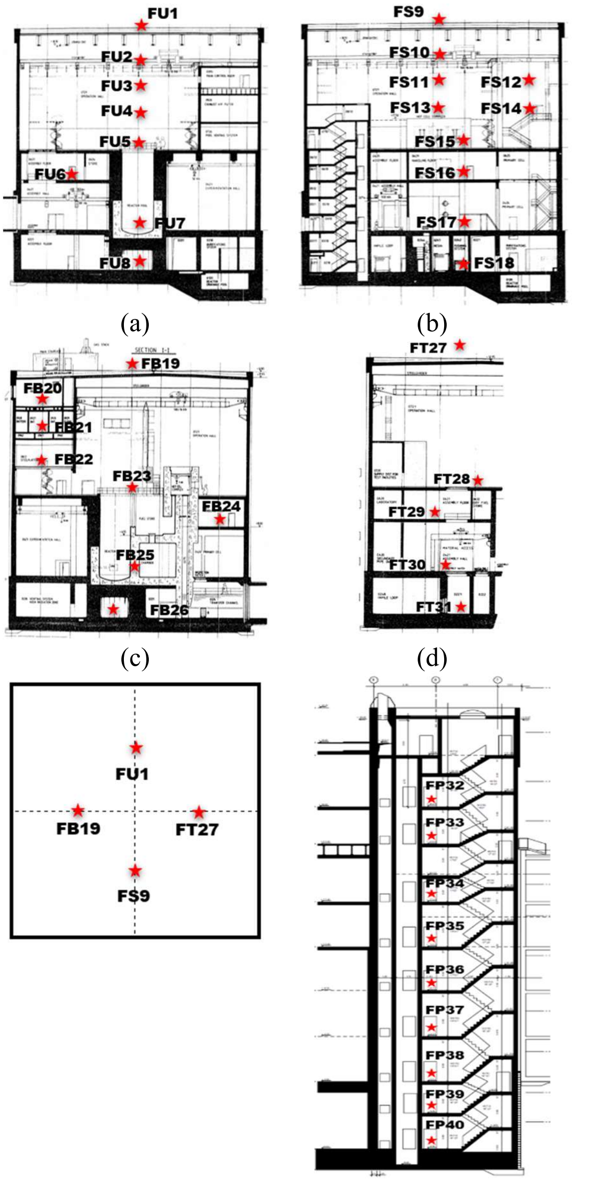


Fig. 3.3. Distribution of FSR data record points in the reactor G.A. Siwabessy building [2]. The picture above is cross-sectional information on the building from various sides (a) north side, (b) south side, (c) west side, (d) east side, (e) top side, (f) distribution of FSR recording points on the stairwell (connecting) at each level.

The data acquisition was carried out when the reactor was inactive period. It is to ensure that the noise source due to the reactor activitis is minimal.

4 Processing of Microseismic Recording Data

The example records are shown in figure 4.1. The records are read by windac software, and convert the records into notepad format. The data in the notepad format is the used for the processing.

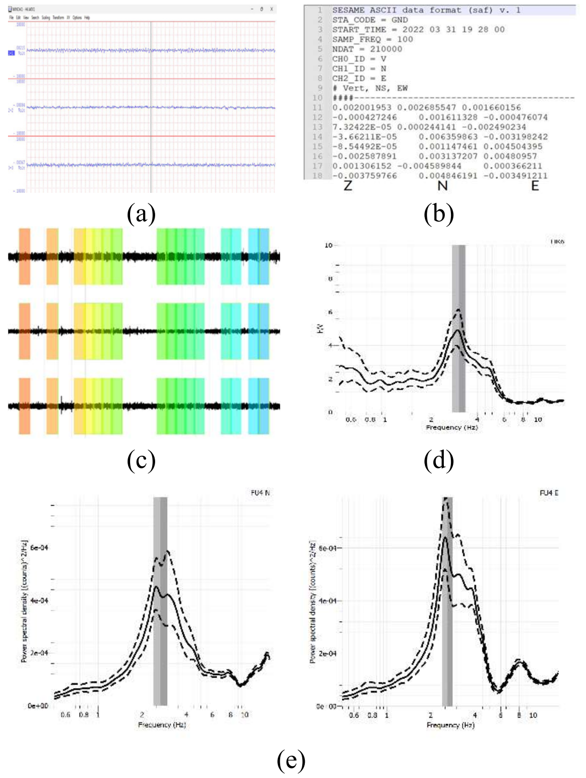


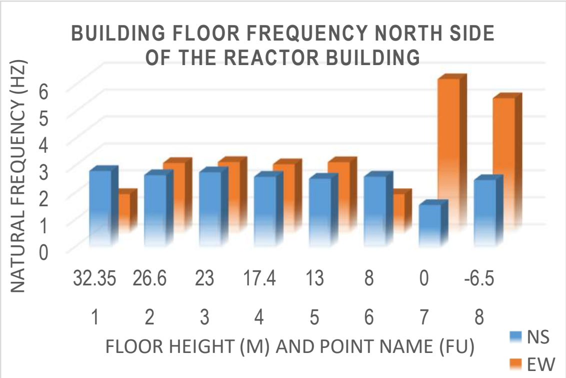
Fig. 4.1. (a) seismograph results of the initial seismometer recording in the form of windac software, (b) conversion results of seismograph data converted into notepad format with classification according to the direction of wave propagation in the form of Z/V, N, E components, (c) windowing process carried out in geopsy software by minimizing seismograph picks which are considered as noise, (d) image results with H/V tools in geopsy for processing outdoor recording data (HVSR), (e) results of data processing in the form of natural frequency values and power spectral density in geopsy software which depicts wave propagation in building structures in the direction of the N and E components.

We processed the recorded data using geopsy software, and we followed the guideline from the SESAME [21]. The following is the result of seismograph recording data processing and has been processed using geopsy software (Table 4.1, Figure 4.2, and Figure 4.4.). For recording data outside the building which was carried out at point C (Figure 3.2) it is processed using the H/V tool so that the following results are obtained,

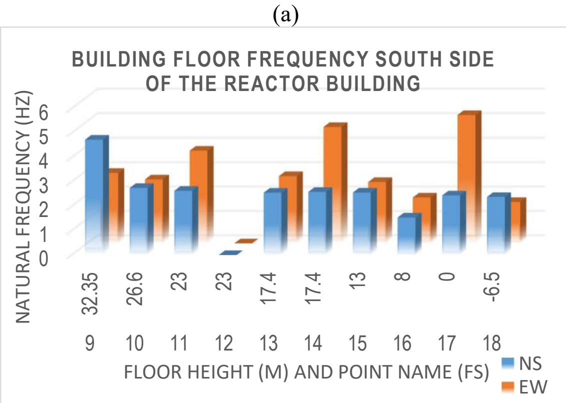
Table 4.1. Data processing result of point C record [20].

Coordinat		Elevation (m)	f_0 (Hz)	A_0
Lat	Long			
-6.352	106.662	52	3.654	2.343

Based on Table 2.1 and Table 2.2, the results of the recording outside the building at point C shows the soil parameters of the G.A. Siwabessy reactor installation is a type III, with a sediment thickness of >5m. While the results of processing seismograph records for building structures processed using the spec tool obtained the following results:



(a)



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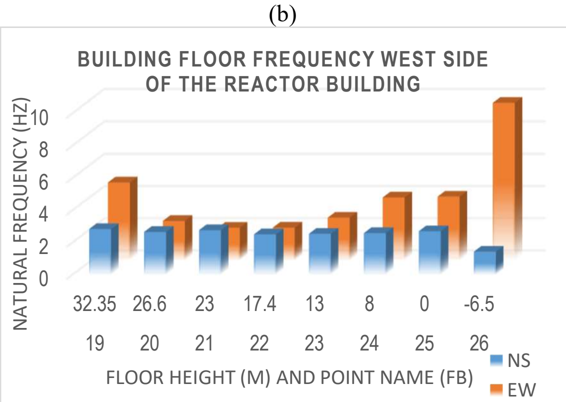

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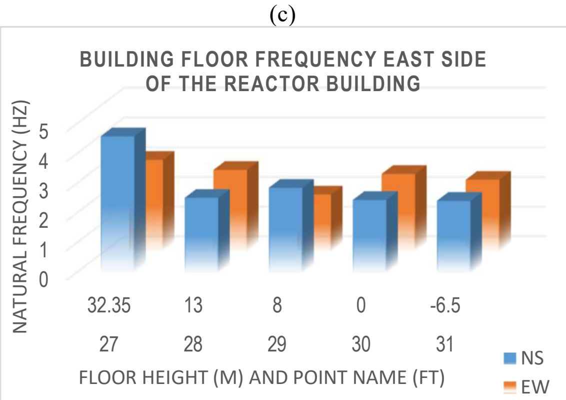

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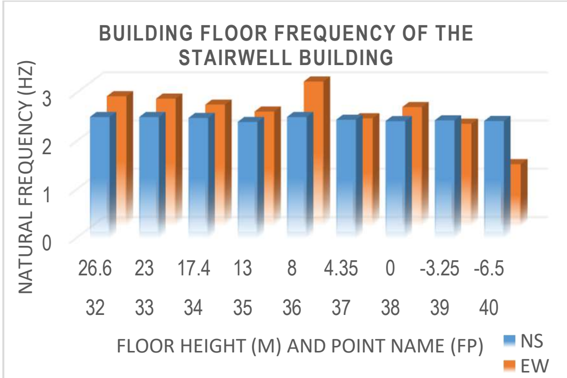


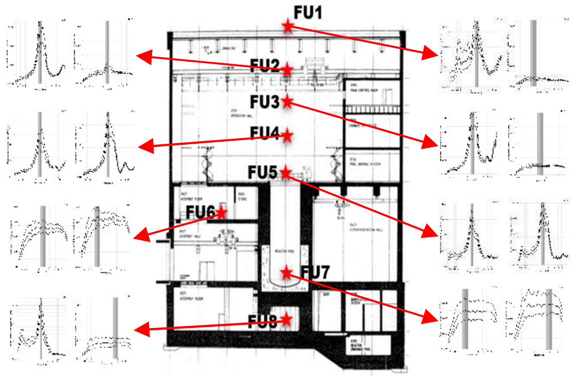
(e)

Fig. 4.2. The results of processing seismograph recordings of building structures (reactor building and stairwell building) using the spec tool in geopsy software to obtain natural frequency values from each side of the building and level according to the presence of existing recording points. (a) north side of the reactor building, (b) south side of the reactor building, (c) west side of the reactor building, (d) east side of the reactor building, (e) stairs building.

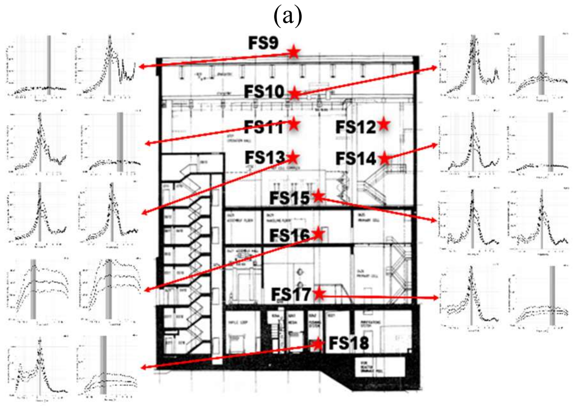
Fig. 4.3. The layer on the floor is located at point FS12, this results in the seismometer not being able to record properly.

We calculated the horizontal spectrum from each measurement location using the spec tool on the geopsy software and the results of these calculations are shown in Figure 4.2. The FS12 recording point could not produce a record, this is because the room where the recording was made at that time has an additional layer (the seismometer cannot touch the floor structure directly) so the seismometer cannot properly record the propagation of waves that propagate on the floor. In addition, it was found that the natural frequency range obtained for wave propagation based on the direction of the NS component was in the range of 1.423 Hz to 4.726 Hz with an average frequency value in that direction of 2.547 Hz. For wave propagation in structures with the direction of the EW component, it has an f_0 value in the range of 1.280 Hz to 9.753 Hz and the average f_0 value in that direction is 2.957 Hz.

Based on the results of data processing in Figure 4.2, Figure 4.4 shows the natural frequencies distribution each floor level of the north side of the G.A. Siwabessy reactor building and stair building with the components for each measurement point consisting of NS and EW components.



(a)



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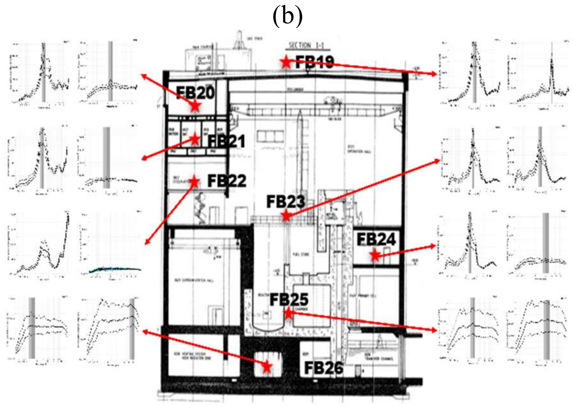

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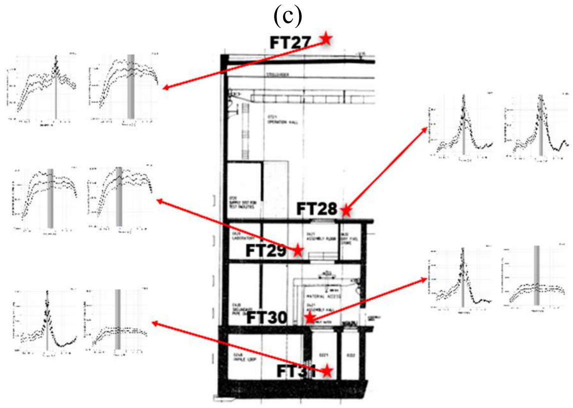

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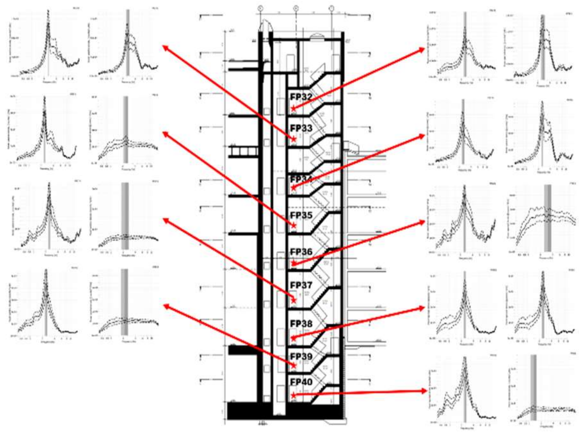

(e)

Fig. 4.4. The distribution of the ellipticity curve for each recording point from the N and E direction components on the reactor building (a) north side, (b) south side, (c) west side, (d) east side, and (e) on the staircase building. The scale on the graph and the position of the points on each side of the reactor building (except the staircase building) have not been adjusted based on the same vertical axis of symmetry.

5 Conclusion

Based on the analysis results obtained, the Horizontal to Vertical Spectral Ratio (HVSR) value and soil characteristics obtained for the f_0 reactor were 3.654 and the A_0 value was 2.343, indicating the appropriate value for building a nuclear facility, especially a nuclear reactor, this is because the A_0 value is at G.A. Siwabessy reactor site is included in the low category. Meanwhile, the characteristic value of f_0 for the reactor building and staircase building structure is in the range 1,423 Hz – 4,726 Hz (NS) with an average (NS) of 2,547 Hz and 1,280 Hz – 9,375 Hz (EW) with an average (EW) of 2,957 Hz. With these results obtained, it can be concluded that the condition of the instalation reactor is not in a condition that requires a recommendation for mitigation or structural engineering, based on the value of the reactor installation site. Meanwhile, for a more in-depth analysis with other physical parameters (the results of the interaction of FSR and HVSR analysis), a more detailed study is needed.

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References

1. USGS, "Search Earthquake Catalog," 19 3. [Online]. Available: https://earthquake.usgs.gov/earthquakes/search/. (2023)
2. LAK RSG-GAS Tim, "Laporan Analisis Keselamatan," PRSG, Tangerang Selatan (2018)
3. BATAN, "Laporan Evaluasi Tapak, Reaktor daya Eksperimental, Kawasan PUSPIPTEK Serpong, III.A.1. Aspek Kegempaan," BATAN, Jakarta (2016)
4. BAPETEN, "Laporan Hasil Evaluasi, Dokumen Laporan Penilaian Keselamatan Berkala," BAPETEN, Jakarta (2017)
5. Okada., The microtremor survey method, Society of Exploration Geophysicists with the cooperation of Society of Exploration Geophysicists of Japan and Australian Society of Exploration Geophysicists (2003)
6. Y. Nakamura, Vulnerability Investigation of Roman Collisseum Using Microtremor (2000)
7. Y. Nakamura, "A Method for Dynamic Characteristics Estimation of Subsurface using Microtremor on the Ground Surface," *QR of RTRI,* vol. **30**, no. 1, p. 25–33 (1989)
8. M. Mokhberi, "Vulnerability evaluation of the urban area using the H/V spectral ratio of microtremors," *International Journal of Disaster Risk Reduction,* vol. **13**, p. 369–374 (2015)
9. Dian-Ping, "Nakamura spectral ratio characteristics of microseism signal induced by relieve-shot," *Procedia Engineering,* vol. **26**, pp. 1296-1304 (2011)
10. Setiawan, Mikrozonasi Seismitas Daerah Yogyakarta Dan Sekitarnya (Tesis), Bandung: Institut Teknologi Bandung (2019)
11. Kanai., "On Microtremors," in *Bulletin of The Earthquake Research Institute*, Earthquake Research Institute (1960)
12. Herak, "Overview of recent ambient noise measurements in Croatia in free-field and in buildings," *Geofizika,* vol. 28 (2011)
13. Herak, "Recent applications of ambient vibration measurements in Croatia, in Increasing Seismic Safety by Combining Engineering Technologies and Seismological Data," in *NATO series*, Dordrecht, p. 281–292 (2009)
14. M. Trifunac, M. Todorovska, "Long period microtremors, microseisms and earthquake damage: Northridge, CA, earthquake of 17 January 1994," *Soil Dyn. Earthq. Eng,* vol. **19**, no. 4, p. 253–267 (2000)
15. E. Haghshenas, P.-Y. Bard, N. Theodulidis, S.W. Team Haghshenas, "Empirical evaluation of microtremor H/V spectral ratio," *Bull. Earthq. Eng,* vol. **6**, no. 1, p. 75–108 (2008)
16. M.R. Gallipoli, M. Mucciarelli, S. Gallicchio, M. Tropeano, C. Lizza, "Horizontal to vertical spectral ratio (HVSR) measurements in the area damaged by the 2002 Molise, Italy, earthquake," *Earthq. Spectra,* vol. **20**, no. S1, p. S81–S93 (2001)
17. M. Mucciarelli, M.R. Gallipoli, M. Arcieri, "The stability of the horizontal-to- vertical spectral ratio of triggered noise and earthquake recordings," *Bull. Seismol. Soc. Am.,* vol. **93**, no. 3, p. 1407–1412 (2003)
18. A. Gosar, J. Rošer, B. Šket Motnikar and P. Zupančič, "Microtremor study of site effects and soil-structure resonance in the city of Ljubljana (central Slovenia)," *B. Earthq. Eng,* vol. **8**, p. 571–592 (2010)
19. A. Gosar, "Site effects and soil-structure resonance study in the Kobarid basin (NW Slovenia) using microtremors," *Nat. Hazards Earth Syst. Sci,* no. 10, p. 761–772 (2010)
20. A. Satriyo, W. Suryanto, T. Anggono, M. Lutfi Al-Kamali, H. Salsalina Yufi, "Kajian Resiko Seismik di Kawasan Nuklir Serpong dengan Studi Horizontal Vertical Spectral Ratio," in *Seminar Keselamatan Nuklir 2023*, Jakarta, (2023) (to be published)
21. SESAME, Site Effects Assessment Using Ambient Excitations. Report of the WP04 H/V Technique : Empirical Evaluation. Deliverable D16.04 (2014)
22. BMKG, "Sumberdaya Geologi," in *Buletin Meteorologi dan Geofisika No.4*, Jakarta, BMKG, (1998)