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ANALYSIS OF VULNERABILITY AND DYNAMIC CHARACTERISTICS OF A MONOLITHIC BUILDING USING MICROTREMOR MEASUREMENTS

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Summary. Microtremor measurements are a widely recognized and effective method for evaluating the dynamic properties and potential seismic vulnerability of buildings. These measurements allow for the determination of critical parameters such as the dominant frequency, amplification factor, vulnerability index, and floor spectral ratio (FSR) for each floor of the building under investigation. In this study, microtremor measurements were conducted on a 26-storey monolithic reinforced concrete residential building located in the heart of Tashkent city. Recordings were made using six velocimeters simultaneously for 30 minutes. Measurements were taken on the basement floors (two floors), on the first floor, and then at two-floor intervals throughout the entire height of the building. Additionally, free-field measurements were taken on the ground outside the building to serve as a reference. The data was analyzed using GEOPSY software, which generated HVSR (Horizontal-to-Vertical Spectral Ratio) curves for the structure. The analysis showed that the building has the appropriate characteristics to effectively absorb seismic impact, indicating that it is well-constructed and capable of withstanding seismic forces. The strong structural integrity, demonstrated through low amplification and vulnerability indices, suggests that the building's design provides adequate protection against potential earthquake damage. These findings contribute to the broader understanding of how microtremor studies can be applied in the seismic evaluation of tall buildings in urban conditions.

1. Introduction

One of the parameters that cause significant damage to buildings and structures are their dynamic and seismic characteristics such as natural frequency, resonance value (Herak, 2011) and building vulnerability index (Nakamura et al., 2000). These parameters can be obtained by recording ambient noise. In this study, a 26-story apartment building was investigated using the microtremor method to obtain the building's safety performance. The main advantages of microtremor analysis are simplicity, efficiency and speed, which provide a reliable, accurate and stable assessment of building vibration modes from low-amplitude excitation.

The eigenfrequency value on soil is determined by processing microtremor data using the HVSR (Horizontal to Vertical Fourier Spectral Ratio) (Gallipoli et al., 2004, Irie et al., 2000, and Konno et al., 1998). The natural frequency value of the building is determined using the FSR (Floor Spectral Ratio) method and the analysis spectrum is obtained from each floor to get the natural frequency value of the building (Oynakov et al., 2023). The building resonance value is determined based on the spectrum for each component (NS and EW). Resonance can be used to determine the level of possibility of a building experiencing resonance during an earthquake. Resonance risk occurs if the dominant periods of the ground and buildings are close to each other. The value of the amplification and natural frequency in soil and buildings can be the value of soil vulnerability analysis, building vulnerability analysis and building resonance (Gosar, 2007).

2. Description of the building

T1 business class residential complex with unique modern architecture will be built in 2021-2024. It is located in the center of Tashkent. Complex T1 consists of 26 floors. The 2-storey basement part of the building is intended for parking, the 1st and 2nd floors – for commercial and domestic services, the 3rd floor – for a terrace with a green area, the 4th-26th floors – for residential apartments. The foundations of the building are 218 reinforced frame piles 30 m long and 1.2 m in diameter driven into stony loess soils. The foundation, measuring 76×25×2 m and weighing 9370 tons, was poured on piles. On its top, the T1 building weighing 50,000 tons was constructed using monolithic frame technology. M600 grade concrete was used in the construction.

3. Microtremor measurements

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 (Hadianfard et al., 2017). Microseismic is a vibration of the Earth. The weak vibration can originate from human activity, ocean waves, wind, traffic and others. Sources of microtremor or microseismic can be divided into natural and artificial sources. Examples of 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 (Nakamura, 2009; Okada, 2003).

Microtremors have been based on ambient noise recordings to determine the dynamical characteristic parameters of buildings. Many researchers reviewed, introduced and applied ambient noise analysis for both purposes. Nakamura et al., 2000; Sato et al., 2008 identified damaged buildings using the vulnerability index of a structure estimated from transfer function parameters.

Microtremors were recorded in different parts of -2F, -1F, 1F, 3F, 6F, 9F, 12F, 15F, 18F, 21F, 24F and roof floors of a T1 business class residential complex (Fig. 1). Free-field measurements were also taken close to the building and at a sufficient distance to avoid its influence. Ambient noise measurements were made using a CMG-6TD seismometer (Guralp, UK). Each sensor provided vibration recording over a wide frequency range from 0.03 to 100 Hz.

Microtremor was recorded in three directions (EW, NS, Z) with a 1/100 second sampling rate. The recording length was 30 minutes because frequencies below 1 Hz were not of interest.

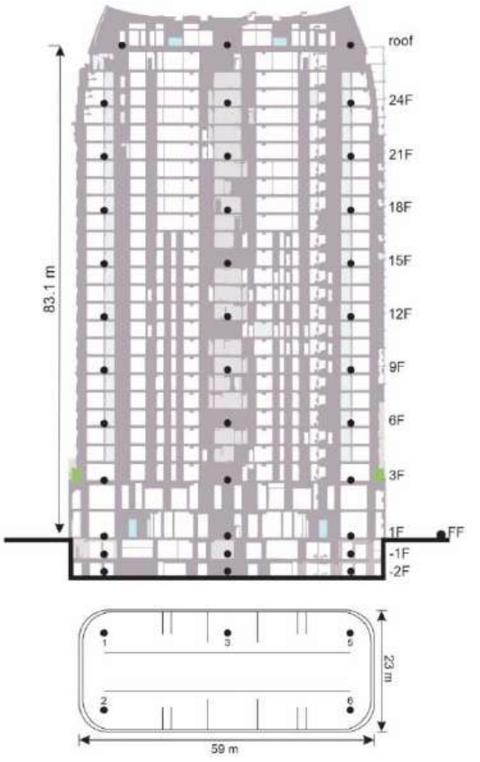


Fig. 1. The elevation and floor plan with measurement points in a newly constructed T1 building. (● - Measurement points)

4. Methodology

4.1. Horizontal to Vertical Spectral Ratio (HVSR)

Microtremor measurements can be utilized to determine the soil's predominant frequency. To prevent the resonance event, a predominant frequency of soil and structure should be calculated and compared. For this purpose, the microtremor HVRS method proposed by Nakamura (Satriyo et al., 2023) was used. To do this, using a seismometer, it is necessary to simultaneously record three components of the ground vibration velocity. Then, power spectra of ground motion should be calculated for two horizontal directions (EW and NS) and also for vertical direction (V). Finally, to determine the site frequency, the spectral ratio of the combined horizontal (H) to vertical (V) component of ground motion must be calculated. The frequency of the peak amplitude in the spectral ratio graph is the predominant (natural) frequency of the site. 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 (Hadianfard et al., 2017).

The following formula is the basis for calculating the horizontal to vertical microtremor spectrum ratio (HVSR) and is expressed as follows:

$$HVSR = \frac{\sqrt{[(S_{north-south})^2+(S_{east-west})^2]}}{S_{vertical}} \quad (1)$$

To obtain reliable HVSR curve results, quality control is required based on the SESAME 2004 standard. There are three reliable criteria for HVSR curves, including (SESAME, 2004):

1. $f_0 > 10/Iw$
2. $nc(f_0) > 200,\ nc = Iw.\ nw.\ f_0,$
3. $\sigma A(f) < 2$ to $0.5f_0 < f < 2f_0$ if $f_0 > 0.5$ Hz, or $\sigma A(f) < 3$ to $0.5f_0 < f < 2f_0$ if $f_0 < 0.5$ Hz

where Iw is the window length, nw is the number of windows selected to obtain the average H/V curve, nc is the number of significant cycles, σA is the standard deviation of A H/V (f), and f_0 is the peak frequency in the H/V curve.

Data processing to obtain the HVSR on the free field was performed in the following way: recorded times series were visually inspected to identify possible erroneous measurements and stronger transient noise. Each record was then split into 20-30 s-long windows tapered with a 5% cosine function. A Fast Fourier Transform (FFT) was calculated for each window in each seismometer component. The Fourier spectra were smoothed using Konno and Ohmachi (Konno et al., 1998) with 40 smoothing constants. HVSR was computed as the geometric average of both horizontal component spectra divided by the vertical spectrum for each window. This analysis was used GEOPSY software.

4.2. Floor Spectral Ratio (FSR)

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 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. (Gallipoli et al., 2004)

The floor spectra ratio (FSR) method is a method for determining the natural and resonant frequencies of buildings that describe the characteristics of buildings against earthquakes (Gosar, 2010; Sungkono et al., 2011). In the FSR method, other building characteristics that can be obtained besides the natural frequency are the building resonance index and the building vulnerability index. The natural frequency building value is determined from the spectrum analysis of each building floor to the ground below it. The data calculation process was performed to determine the natural frequency value of the building using the equation below (Prakosa et. al., 2015).

$$f_0(FSR) = \frac{f_b NS}{f_t NS} = \frac{f_b EW}{f_t EW} \quad (2)$$

Equation (2) is the FSR analysis equation where f_b is the value of the building frequency, f_t is the value of the ground frequency, and NS-EW is the respective components of the data.

Resonance can be used to determine the level of possibility of a building experiencing resonance during an earthquake (Gosar, 2010). There are several classifications:

1. Low resonance (R>25%)
2. Medium resonance (15% <R< 25%)
3. High resonance (R<15%)

The building resonance index (R) is determined based on the spectrum of each component (NS and EW) which is calculated based on the following equation:

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

where f_b is the natural frequency of the building, and f_t is the natural frequency of the ground.

4.3. Vulnerability index

The vulnerability of buildings is one of the most important parameters for the evaluation of potential damages in urban areas caused by earthquakes. Nakamura et al. and Sato et al. showed that the vulnerability index can be used to describe the building strength in bearing the earthquake shakings. It is considered that the vulnerability of structures against earthquake disasters can be estimated by the drift angle, related to the input earthquake acceleration a in cm/s^2. Here, α is a portion that affects this structure among whole earthquake motion a:

$$\alpha = e \times a, \quad (4)$$

where e shows the efficiency of earthquake motion working for this structure.

A deformation performance and the degree of earthquake motion amplification can be estimated from the dynamic characteristics of structures. Here, the primary natural frequency of the structure that seems to influence earthquake damage is considered. Displacement δ_i of ith floor is estimated from this primary natural frequency F and amplitude A_i of ith floor as follows (Fig. 2):

$$\delta_j = A_i \times \alpha/(2\pi F_s)^2 \qquad (5)$$

Therefore, the drift angle γ_i of ith floor is shown as:

$$\begin{aligned}\gamma_i = \delta_{i+1} - \delta_i/h &= \Delta A_i \times \alpha/(2\pi F)^2/h_i \\ &= e \times K_{bi} \times a, \qquad (6)\end{aligned}$$

where

$$K_{bi} = \Delta A_i/(2\pi F)^2/h_i \times 10{,}000, \qquad (7)$$

$$\Delta A_i = A_{i+1} - A_i, \qquad (8)$$

ΔA_i shows the difference in amplification of the ith floor, h_i is the height of ith floor in meters, and F is the predominant frequency of the structure.

Thus, the drift angle γ_i for each floor is estimated from the vulnerability index K_{bi} multiplied by the maximum acceleration on the surface ground in cm/s^2 and the efficiency e of earthquake motion. Here, the ${}_{av}K_b$ value is derived as averaged K_{bi} for each structure for the discussion as follows:

$${}_{av}K_b = \frac{A}{(2\pi F)^2 \times H} \times 10{,}000, \qquad (9)$$

where A – shows the amplitude of the top floor and H – is the total height of the structure in meters.

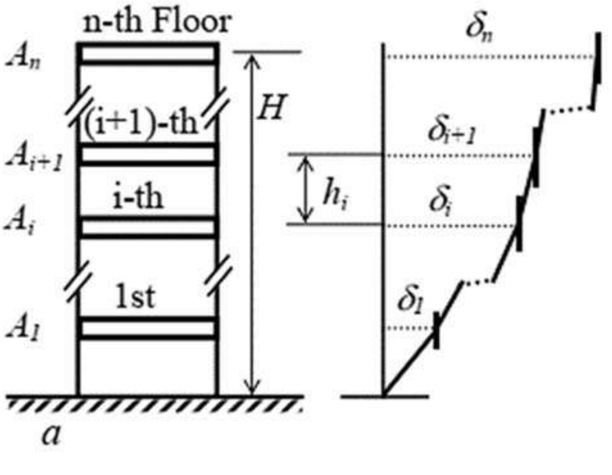


Fig. 2. Schematic model of n-th floor structures and its mode shape. δ_j is the horizontal displacement, h_i is the height, A_i is the amplification factor of the i-th story column, H is the height of the n-th floor structure, and a is the horizontal acceleration of the foundation ground

In addition, when ${}_{av}K_b$ is substituted for K_{bi} in Eq. (6), the averaged drift angle γ_{av} will be calculated. K_{bi} and ${}_{av}K_b$ are expressed in units of 10^{-6}, 10,000 in Eqs. (7) and (9) are multiplied for adjustment.

5. Result of analysis

5.1. Ground natural frequency

Ground natural frequency obtained from HVSR analysis is the average frequency of each vertical and horizontal spectrum. The obtained spectral ratio for the site where the T1 building is located is shown in Fig. 3. Based on this figure, the natural frequency of the site is 0.64 Hz.

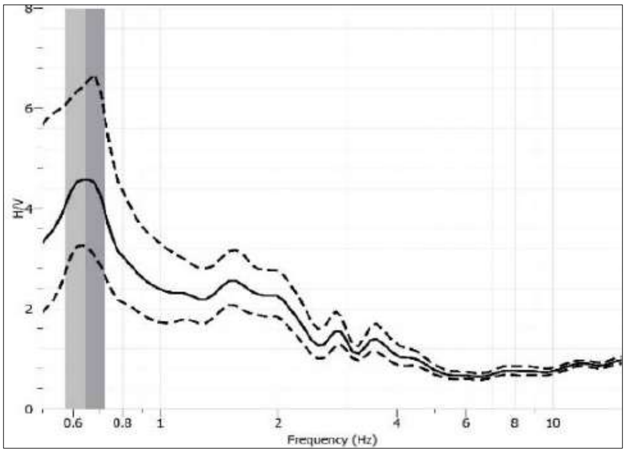


Fig. 3. Spectral ratio (H/V) for site where the T1 building is located, natural frequency 0.64 Hz

5.2. Spectrum analysis of building

Based on the analysis of microtremors recorded in the building, a spectral analysis of the horizontal components of the indicated floors was performed (Fig. 4). The values of the EW component ranged from 0.62-3.1 Hz, and the values of the NS component ranged from 0.64-3.16 Hz. The average frequency spectrum of each component was ± 1.6 Hz. In Fig. 5 it can be observed that the frequency values by floor decrease sharply after the 12th floor because the higher the building, the lower the dominant frequency of the building.

5.3. Floor Spectral Ratio Analysis

FSR (Floor Spectral Ratio) analysis was conducted to determine the natural frequency of the building (Fig. 6). The FSR analysis was calculated by dividing the dominant frequencies of the building floors determined from the spectrum analysis by the free surface frequency.

The EW component values of all floors ranged from 0.97-4.8 Hz, and the NS component values ranged from 1-4.95 Hz. The average natural frequency of each component was ±2.5 Hz.

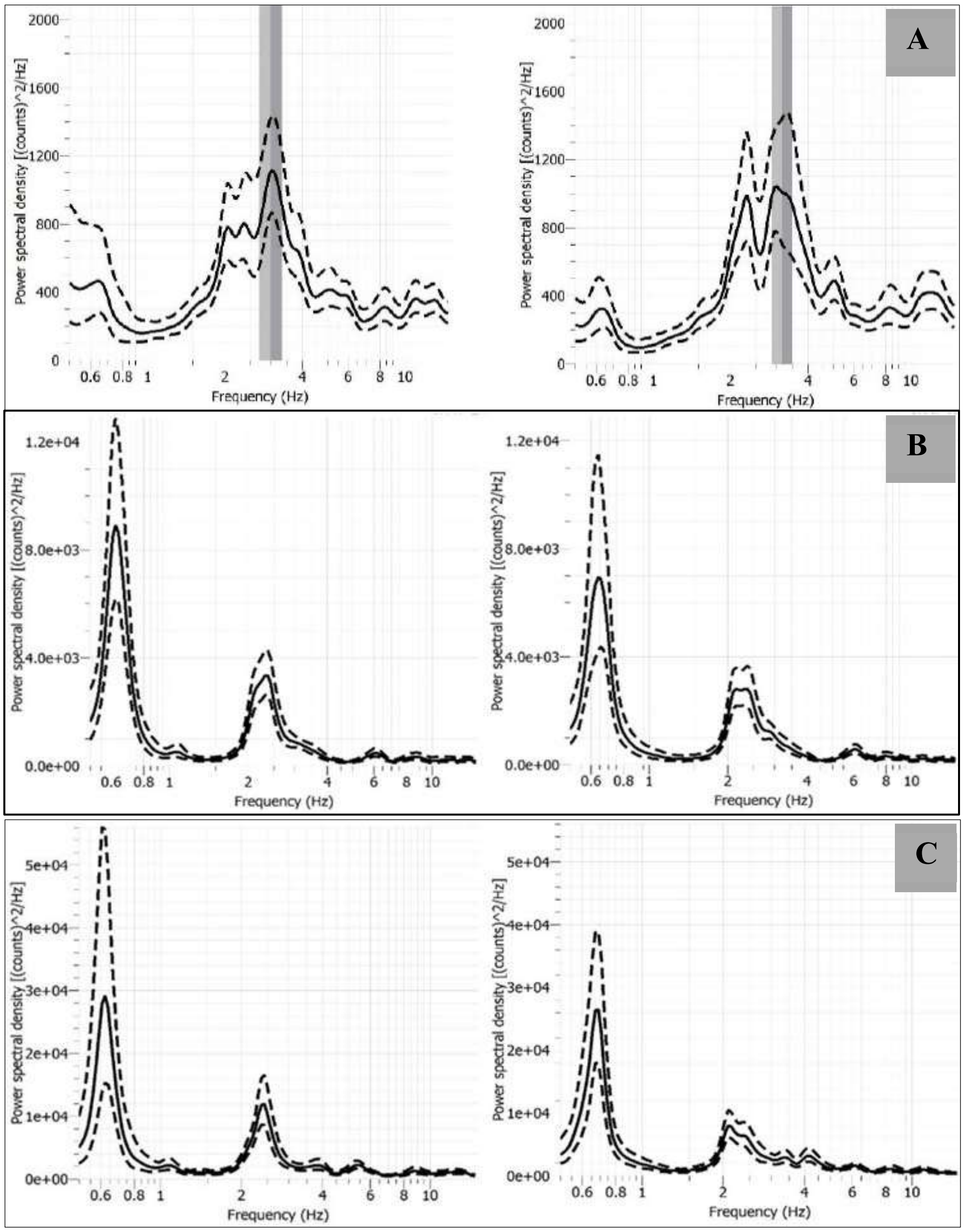
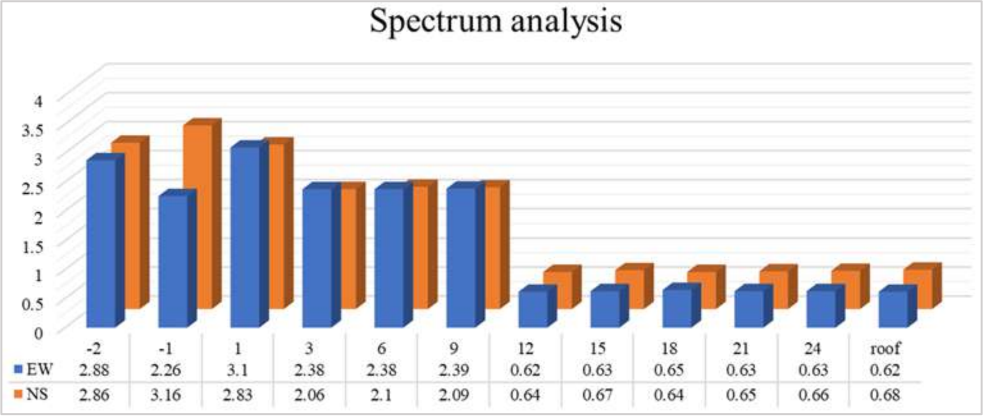


Fig. 4. Frequency and amplitude graph using spectrum analysis. A) EW and NS spectrum graph of the 3rd floor; B) EW and NS spectrum graph of the 12th floor; C) EW and NS spectrum graph of the roof.



	-2	-1	1	3	6	9	12	15	18	21	24	roof
■ EW	2.88	2.26	3.1	2.38	2.38	2.39	0.62	0.63	0.65	0.63	0.63	0.62
■ NS	2.86	3.16	2.83	2.06	2.1	2.09	0.64	0.67	0.64	0.65	0.66	0.68

Fig. 5. Diagram of change of frequency values by floors based on spectral analysis

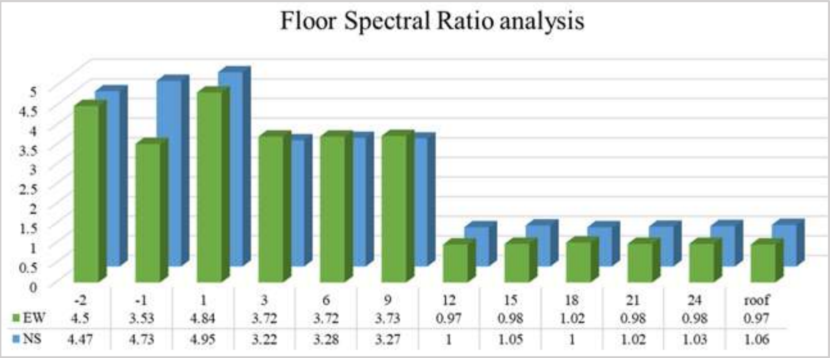


Fig. 6. Diagram of natural frequency variation by floors based on FSR analysis

5.4. Ground and Building resonance

The magnitude of building-to-site resonance ranged from 51% to 617% for the EW component and 59% to 674% for the NS component (Fig. 7). The average resonance value is ±290%. Based on the above classification (Gosar, 2010), the obtained resonance value is categorized as low resonance because the natural frequency of the building is much higher than the value of the natural frequency of the site. For the horizontal components, resonance values up to the 9th floor differed by values greater than >100%, and from the 12th floor and above, values differed by values below <100%. This significantly reduces the probability of resonance phenomenon.

5.5. Building vulnerability index

The building vulnerability index (Kb) shows the level of damage that occurs to the building in the event of an earthquake. The greater the vulnerability value of a building, the greater the potential damage that will occur (Mokhberi, 2015; Sarkowi et al., 2022).

Based on the processing results, the vulnerability index values of building T1 changed from 0.42 to 9.45 for the EW component and from 0.43 to 7.12 for the NS component. The lowest vulnerability index was observed on the 9th floor and the highest on the roof (Fig. 8). This indicates that the building is very resistant to earthquakes.

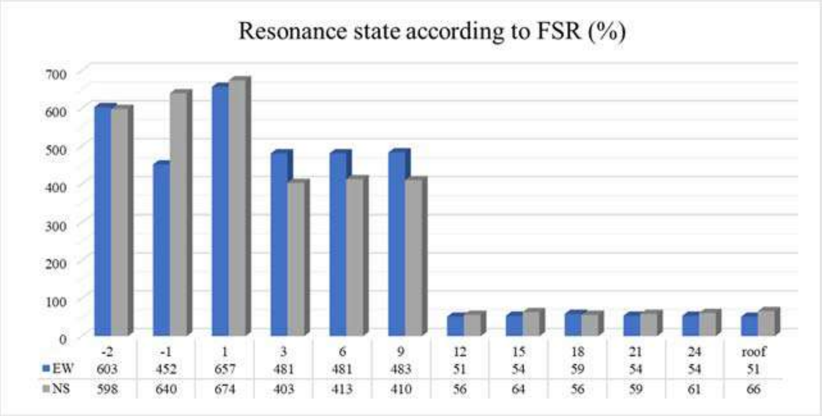


Fig. 7. Diagram of resonance variation by floor

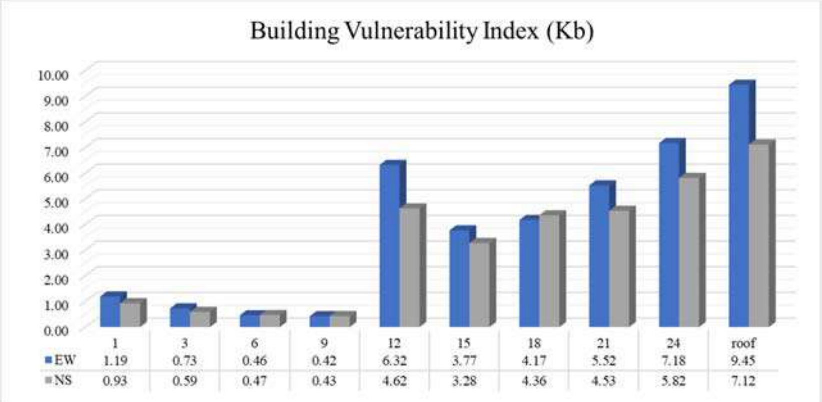


Fig. 8. Diagram of change of vulnerability index by floors

6. Conclusions

Based on the results of calculations and analysis, the soil on which building T1 is located is found to have a frequency of 0.64 Hz by the HVSR method. The FSR analysis showed that the natural frequency of the building was determined to be 0.97 Hz – 4.8 Hz in the EW component and 1 Hz – 4.95 Hz in the NS component. It should be said that above the 9th floor, there was a sharp decrease in the natural frequency of the building. This indicates that the building was divided into two parts.

The magnitude of the building and ground resonance varied between 51% – 617% in the EW component and between 59% – 674% in the NS component. The mean value of the component resonance was ±290%. In turn, this figure is categorized as low resonance because the natural frequency of the building is much higher than the value of the natural frequency of the ground.

The vulnerability index ranged from 0.42 to 9.45 for the EW component and from 0.43 to 7.12 for the NS component. The vulnerability index values decreased from the 1st floor to the 9th floor and increased sharply from the 9th floor above. In general, the values showed a result below <10. The vulnerability index value of the building shows that the building is of low category (safe).

REFERENCES

Gallipoli M.R., Mucciarelli M., Castro R.R., Monachesi G., Contri P. Structure, soil-structure response and effects of damage based on observations of horizontal-to-vertical spectral ratios of microtremors. Soil Dynamics and Earthquake Engineering, Vol. 24(6), 2004, pp. 487-495, DOI:10.1016/j.soildyn.2003.11.009.

Gosar A. Microtremor HVSR study for assessing site effects in the Bovec basin (NW Slovenia) related to 1998 Mw5.6 and 2004 Mw5.2 earthquakes. Engineering Geology, Vol. 91, No. 2-4, 2007, pp. 178-193, DOI:10.1016/j.enggeo.2007.01.008.

Gosar A. Site effects and soil-structure resonance study in the Kobarid basin (NW Slovenia) using microtremors. Natural Hazards and Earth System Science, Vol. 10(4), 2010, pp. 761-772, DOI:10.5194/nhess-10-761-2010.

Hadianfard M.A., Rabiee R., Sarshad A. Assessment of vulnerability and dynamic characteristics of a historical building using microtremor measurements. Journal of Civil Engineering, Vol. 15, 2017, pp. 175-183, https://doi.org/10.1007/s40999-016-0086-2.

Herak M. Overview of recent ambient noise measurements in Croatia in free-field and in buildings Geofizika, Vol. 28(1), 2011, pp.21-37.

Irie Y., Nakamura K. Dynamic characteristics of a R/C building of five stories based on microtremor measurements and earthquake observations. In: Proc. of XII World. Conf. Earthq. Eng., Wellington, 2000, pp. 500-508.

Konno K. and Ohmachi T. Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. Bulletin of the Seismological Society of America, Vol. 88, No.1, 1998, pp. 228-241, https://doi.org/10.1785/BSSA0880010228.

Mokhberi M. Vulnerability evaluation of the urban area using the H/V spectral ratio of microtremors. International Journal of Disaster Risk Reduction, Vol. 13, 2015, pp. 369-374, DOI:10.1016/j.ijdrr.2015.06.012.

Nakamura Y, Gurler E.D., Saita J., Rovelli A., Donati S. Vulnerability investigation of roman colosseum using Microtremor. In: 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 2000, pp. 2660-1-8.

Nakamura Y. Basic Structure of QTS (HVSR) and Examples of Applications. In: Increasing Seismic Safety by Combining Engineering Technologies and Seismological Data, Conference proceedings, edited by Mucciarelli M. et al., Dordrecht, Netherlands, 2009, pp. 33-51, DOI:10.1007/978-1-4020-9196-4.

Okada H. The microtremor survey method. Society of Exploration Geophysicists with the cooperation of Society of Exploration Geophysicists of Japan and Australian Society of Exploration Geophysicists, SEG Books. Science. 2003, 135 p.

ЛИТЕРАТУРА

Gallipoli M.R., Mucciarelli M., Castro R.R., Monachesi G., Contri P. Structure, soil-structure response and effects of damage based on observations of horizontal-to-vertical spectral ratios of microtremors. Soil Dynamics and Earthquake Engineering, Vol. 24(6), 2004, pp. 487-495, DOI:10.1016/j.soildyn.2003.11.009.

Gosar A. Microtremor HVSR study for assessing site effects in the Bovec basin (NW Slovenia) related to 1998 Mw5.6 and 2004 Mw5.2 earthquakes. Engineering Geology, Vol. 91, No. 2-4, 2007, pp. 178-193, DOI:10.1016/j.enggeo.2007.01.008.

Gosar A. Site effects and soil-structure resonance study in the Kobarid basin (NW Slovenia) using microtremors. Natural Hazards and Earth System Science, Vol. 10(4), 2010, pp. 761-772, DOI:10.5194/nhess-10-761-2010.

Hadianfard M.A., Rabiee R., Sarshad A. Assessment of vulnerability and dynamic characteristics of a historical building using microtremor measurements. Journal of Civil Engineering, Vol. 15, 2017, pp. 175-183, https://doi.org/10.1007/s40999-016-0086-2.

Herak M. Overview of recent ambient noise measurements in Croatia in free-field and in buildings Geofizika, Vol. 28(1), 2011, pp.21-37.

Irie Y., Nakamura K. Dynamic characteristics of a R/C building of five stories based on microtremor measurements and earthquake observations. In: Proc. of XII World. Conf. Earthq. Eng., Wellington, 2000, pp. 500-508.

Konno K. and Ohmachi T. Ground-motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremor. Bulletin of the Seismological Society of America, Vol. 88, No.1, 1998, pp. 228-241, https://doi.org/10.1785/BSSA0880010228.

Mokhberi M. Vulnerability evaluation of the urban area using the H/V spectral ratio of microtremors. International Journal of Disaster Risk Reduction, Vol. 13, 2015, pp. 369-374, DOI:10.1016/j.ijdrr.2015.06.012.

Nakamura Y, Gurler E.D., Saita J., Rovelli A., Donati S. Vulnerability investigation of roman colosseum using Microtremor. In: 12th World Conference on Earthquake Engineering, Auckland, New Zealand, 2000, pp. 2660-1-8.

Nakamura Y. Basic Structure of QTS (HVSR) and Examples of Applications. In: Increasing Seismic Safety by Combining Engineering Technologies and Seismological Data, Conference proceedings, edited by Mucciarelli M. et al., Dordrecht, Netherlands, 2009, pp. 33-51, DOI:10.1007/978-1-4020-9196-4.

Okada H. The microtremor survey method. Society of Exploration Geophysicists with the cooperation of Society of Exploration Geophysicists of Japan and Australian Society of Exploration Geophysicists, SEG Books. Science. 2003, 135 p.

Oynakov E., Ivanov R., Aleksandrova I., Milkov J., Popova M. Evaluation of the Nakamura vulnerability index of a cast-in-situ reinforced-concrete building from ambient noise records. In: Dobrinkova, N., Nikolov, O. (eds.) Environmental Protection and Disaster Risks. EnviroRISKs 2022. Lecture Notes in Networks and Systems, Vol. 638. Springer. Cham. 2023, pp.66-76, DOI:10.1007/978-3-031-26754-3_6.

Prakosa P.T., Ibad M.I., Kafi M.S., Burhanudin M.A., Rahmania A. (2015) Earthquake microzonation and strength building evaluation at Gelora Bung Tomo Stadium Surabaya using micro-tremor method. Proceedings of 7th International Conference on Physics and Its Applications 2014 (ICOPIA 2014), Vol. 1, 2015, pp. 14-20.

Sarkowi M., Wibowo R.C., Sunanda Yogi I.B., Yusuf M., Boka Y.S. Microtremor analysis to evaluate BMKG region III building, Bali, Indonesia. IJES – Iranian Journal of Earth Sciences, Vol. 14(2), 2022, 104-111, DOI: 10.30495/ijes.2022.1942485.1659.

Sato T., Nakamura Y., Saita J. The change of dynamic characteristics using microtremor. The 14th WCEE – The 14th World Conference on Earthquake Engineering, Beijing, China, 2008, pp 17-25.

Satriyo A., Suryanto W., Anggono T., Al Kamali M.L., Yufi H.S. Study Characteristics of a Multipurpose Reactor Building G.A. Siwabessy using Floor Spectral Ratio. E3S Web of Conferences. Vol. 468, 2023, ICST UGM –The 4th Geoscience and Environmental Management Symposium, Article Number 09003, 2023, https://doi.org/10.1051/e3sconf/202346809003.

SESAME, Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations measurements, processing and interpretation, 2004, Available: http://sesame-fp5.obs.ujfgrenoble.fr/Delivrables/Del-D23HVUser Guidelines.pdf.

Sungkono S., Warnana D.D., Triwulan, Utama W. Evaluation of Buildings Strength from Microtremor Analyses. International Journal of Civil & Environmental Engineering, Vol. 11(05), 2011, pp. 6-12.

Oynakov E., Ivanov R., Aleksandrova I., Milkov J., Popova M. Evaluation of the Nakamura vulnerability index of a cast-in-situ reinforced-concrete building from ambient noise records. In: Dobrinkova, N., Nikolov, O. (eds.) Environmental Protection and Disaster Risks. EnviroRISKs 2022. Lecture Notes in Networks and Systems, Vol. 638. Springer. Cham. 2023, pp.66-76, DOI:10.1007/978-3-031-26754-3_6.

Prakosa P.T., Ibad M.I., Kafi M.S., Burhanudin M.A., Rahmania A. (2015) Earthquake microzonation and strength building evaluation at Gelora Bung Tomo Stadium Surabaya using micro-tremor method. Proceedings of 7th International Conference on Physics and Its Applications 2014 (ICOPIA 2014), Vol. 1, 2015, pp. 14-20.

Sarkowi M., Wibowo R.C., Sunanda Yogi I.B., Yusuf M., Boka Y.S. Microtremor analysis to evaluate BMKG region III building, Bali, Indonesia. IJES – Iranian Journal of Earth Sciences, Vol. 14(2), 2022, 104-111, DOI: 10.30495/ijes.2022.1942485.1659.

Sato T., Nakamura Y., Saita J. The change of dynamic characteristics using microtremor. The 14th WCEE – The 14th World Conference on Earthquake Engineering, Beijing, China, 2008, pp 17-25.

Satriyo A., Suryanto W., Anggono T., Al Kamali M.L., Yufi H.S. Study Characteristics of a Multipurpose Reactor Building G.A. Siwabessy using Floor Spectral Ratio. E3S Web of Conferences. Vol. 468, 2023, ICST UGM –The 4th Geoscience and Environmental Management Symposium, Article Number 09003, 2023, https://doi.org/10.1051/e3sconf/202346809003.

SESAME, Guidelines for the implementation of the H/V spectral ratio technique on ambient vibrations measurements, processing and interpretation, 2004, Available: http://sesame-fp5.obs.ujfgrenoble.fr/Delivrables/Del-D23HVUser Guidelines.pdf.

Sungkono S., Warnana D.D., Triwulan, Utama W. Evaluation of Buildings Strength from Microtremor Analyses. International Journal of Civil & Environmental Engineering, Vol. 11(05), 2011, pp. 6-12.

АНАЛИЗ УЯЗВИМОСТИ И ДИНАМИЧЕСКИХ ХАРАКТЕРИСТИК МОНОЛИТНОГО ЗДАНИЯ С ИСПОЛЬЗОВАНИЕМ МИКРОТРЕМОРНЫХ ИЗМЕРЕНИЙ

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Резюме. Микротреморные измерения являются одним из наиболее эффективных и широко применяемых методов для оценки динамических характеристик зданий и определения их сейсмической уязвимости. Данный метод позволяет выявить ключевые параметры, такие как доминирующая частота, коэффициент усиления, индекс уязвимости, а также спектральное отношение (FSR) для каждого отдельного этажа здания. В рамках данного исследования были проведены измерения на 26-этажном монолитном железобетонном жилом здании, расположенном в центре города Ташкент. Для получения данных использовались шесть велосиметров, работающих одновременно в течение 30 минут для повышения точности результатов. Измерения проводились на этажах подвала (два этажа), на первом этаже, а также на каждом втором этаже по высоте здания. Кроме того, были проведены непрерывные измерения на свободной поверхности вокруг здания для сравнительного анализа с грунтом и изучения поведения основания при сейсмическом воздействии. Данные были обработаны с использованием программного пакета GEOPSY, который позволил построить кривые HVSR (горизонтально-вертикальные спектральные отношения). Анализ показал, что здание обладает соответствующими характеристиками эффективно гасить сейсмическое воздействие, что свидетельствует о его прочной конструкции и способности противостоять сейсмическим нагрузкам. Низкий коэффициент усиления и индекс уязвимости указывают на высокую устойчивость здания к потенциальным сейсмическим воздействиям, что подтверждает его способность выдерживать землетрясения. Эти выводы являются значительным вкладом в понимание важности применения микротреморных исследований для сейсмической оценки высотных зданий, особенно в условиях плотной городской застройки и повышенной сейсмической активности.

Ключевые слова: *микротремор, собственная частота, FSR, HVSR, индекс уязвимости, резонанс*

MİKROTREMOR OLÇÜLMƏLƏRİNDƏN İSTİFADƏ ETMƏKLƏ MONOLİT BİNALARIN DAVAMLIĞININ VƏ DİNAMİK XÜSUSİYYƏTLƏRİNİN TƏHLİLİ

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Xülasə. Mikrotremor ölçmələri binaların dinamik səciyyələrinin qiymətləndirilməsi və onların seysmik həssaslığının müəyyən edilməsi üçün ən təsirli və geniş istifadə olunan metodlardan biridir. Bu metod dominant tezlik, gücləndirmə əmsalı, həssaslıq indeksi və hər bir mərtəbə üçün spektral nisbət (FSR) kimi əsas parametrləri müəyyən etməyə imkan verir. Bu tədqiqat çərçivəsində ölçmələr Daşkənd şəhərinin mərkəzində yerləşən 26 mərtəbəli monolit dəmir-beton yaşayış binasında aparılmışdır. Məlumatların toplanması üçün eyni vaxtda 30 dəqiqə ərzində işləyən altı velosimetrdən istifadə edilmişdir ki, nəticələrin dəqiqliyi artsın. Ölçmələr zirzəmi mərtəbələrində (iki mərtəbə), birinci mərtəbədə və bina boyunca hər iki mərtəbədə aparılmışdır. Bundan əlavə, qeyd etmək lazımdır ki, torpaq ilə müqayisəli analiz aparmaq məqsədilə və həmçinin təməl seysmik təsir altında bazanın davranışını öyrənmək üçün binanın ətrafındakı sərbəst səthdə davamlı ölçmələr aparılmışdır. Nəticələr GEOPSY proqram təminatı vasitəsilə işlənilmişdir ki, bu da HVSR (horizontal-vertikal spektral nisbətlər) əyrilərinin qurulmasına imkan verir. Analiz göstərdi ki, bina seysmik təsirləri effektiv şəkildə zəiflədə bilir, bu da onun möhkəm quruluşa malik olduğunu və seysmik yüklərə davam gətirə biləcəyini sübut edir. Aşağı gücləndirmə əmsalı və həssaslıq indeksi binanın potensial seysmik təsirlərə qarşı dayanıqlığını göstərir və onun zəlzələlərə qarşı davamlı olduğunu təsdiq edir. Bu nəticələr mikrotremor tədqiqatlarının hündür binaların seysmik qiymətləndirilməsində tətbiqinin əhəmiyyətini anlamağa, xüsusilə sıx şəhərsalma və yüksək seysmik aktivlik şəraitində böyük töhfə verir.

Açar sözlər: *mikrotremor, xüsusi tezlik, FSR, HVSR, zəiflilik indeksi, rezonans*