International Journal of GEOMATE
(Geotechnique, Construction Materials and Environment)
ISSN: 2186-2982 (P), 2186-2990 (O), Japan

Vol. 31, Issue 144, August, 2026, PP.61-69; DOI: 10.21660/2026.144.5483

A COMPARATIVE STUDY OF PASSIVE SEISMIC APPROACHES FOR MULTI-STORY BUILDING FUNDAMENTAL FREQUENCY IDENTIFICATION

Juellyan Iskandar[1,2], *Bambang Setiawan[3], Muttaqin Hasan[4], Ashfa Achmad[5], Alfiansyah Yulianur[4]

[1]Doctoral Program, School of Engineering, Post Graduate Program, Universitas Syiah Kuala, Indonesia; [2]Awardee, Program Riset Unggulan Universitas Syiah Kuala Percepatan Doktor (PRUU-PD) Lembaga Penelitian dan Pengabdian kepada Masyarakat (LPPM), Universitas Syiah Kuala, Indonesia; [3]Program Study of Geological Engineering, Faculty of Engineering, Universitas Syiah Kuala, Indonesia; [4]Civil Engineering Department, Faculty of Engineering, Universitas Syiah Kuala, Indonesia; [5]Architecture and Planning Department, Faculty of Engineering, Universitas Syiah Kuala, Indonesia.

*Corresponding Author, Received: 13 Feb. 2026, Revised: 27 April 2026, Accepted: 07 May 2026

ABSTRACT: Resonance due to earthquakes can significantly increase the likelihood of multi-story buildings collapsing; therefore, a reliable identification of the fundamental frequency is critical for estimating the building's seismic performance. This study investigates the fundamental frequency by means of three different passive seismic approaches, i.e., the horizontal-to-vertical spectral ratio (HVSR), the floor spectral ratio (FSR) and the random decrement method (RDM). Ambient vibrations recorded on multiple floors in 12 multi-story buildings located in Aceh Province, Indonesia, were used in the present study. Initially, signal stability was assessed qualitatively through waveform continuity, spectral repeatability, and visual inspection of inter-channel consistency. Windows affected by impulsive disturbances or unstable spectral characteristics were excluded before further analysis by means of HVSR, FSR, and RDM. The findings suggest that the HVSR approach always suggests the lowest frequency compared to the others. Furthermore, HVSR seems sensitive to vertical motion, instead of the horizontal structural response. HVSR is likely also sensitive to soil-layer resonance and soil–structure interaction. This study finds that FSR and RDM are effective at capturing the inherent fundamental frequencies of buildings. Both FSR and RDM suggest well-matched building frequency estimation. In conclusion, the applied approaches in the present study offer a straightforward conceptual framework for assessing building dynamic parameters in site-specific environments.

Keywords: Ambient noise, Structural natural frequency, HVSR, FSR, RDM.

1. INTRODUCTION

Understanding the dynamic response of buildings is crucial for seismic risk mitigation and seismic-resistant design on building structures. In the dynamic assessment, resonance between the structural frequency and seismic ground motion is particularly important because it can amplify structural response and increase the potential for the building to be damaged. In this case, an accurate quantification of both fundamental frequency and damping ratio is essential for seismic performance evaluation, structural retrofitting, and seismic disaster mitigation. Many previous studies have demonstrated that the interaction of vibration input (i.e., seismic waves), structural properties, and local soil conditions controls structural response [1–3].

Limitations of the current applied methods, such as forced vibration testing and numerical modelling, include the need for specialized equipment, a relatively long testing duration, and a tendency toward simplification. Earlier studies using forced and earthquake records found that the fundamental or natural frequency and damping change with input amplitude, as well as with cracking, stiffness degradation, and mass/lateral resistance distribution [4–6]. As a result, the use of ambient vibration or passive seismic measurements has become popular, as these tests are non-destructive, economical, and enable characterization of structural dynamics under serviceability conditions without disrupting daily building operations [1, 4]. Ambient vibration studies have also revealed that resonance computed from passive seismic data in urban basins might reflect not only building behavior [7], but also local site effects and soil-structure interaction, even in areas where soft deposits or significant impedance contrasts exist [8–16]. However, much of these previous ambient vibration works has been limited to one building, one processing technique, or only site-effect analysis (site effect), and currently, limited studies have been published on a comparison of several passive seismic approaches for a specific building type under similar environmental conditions.

In the passive seismic method, the horizontal-to-vertical spectral ratio (HVSR) approach has been widely used to obtain site-dominant or fundamental resonance frequencies. Initially, this HVSR approach has been extensively applied for site-effect analysis, but more recently, this approach has also been used for dynamic characterization of civil structures [4, 7, 17]. HVSR approach justifies resonance by comparing the horizontal and vertical components of seismic signals at a single location, highlighting predominant periods influenced by soil or the structure itself. The floor spectral ratio (FSR) approach, in contrast, evaluates structural response by comparing the spectral amplitudes at each floor with those at a chosen reference level within the building. This approach is enabling the identification of modal frequencies and floor-to-floor amplification patterns [8, 9, 18]. This FSR focuses on internal structural dynamics rather than ground influence. The random decrement method (RDM) differs by extracting free-decay responses from time-domain ambient vibration data to directly estimate both natural frequency and damping ratio [18]. Thus, HVSR emphasizes soil and overall resonance, FSR focuses on floor-level internal dynamics, and RDM targets direct dynamic property estimation. The present study applied these three approaches complementing each other in describing a structure's dynamic behavior for design purposes. This study also compares HVSR, FSR, and RDM at different floors of the measured building. The performance, advantages, and disadvantages of each approach is outlined to provide practical recommendations for future dynamic characterization and seismic assessment of multi-story structures.

2. RESEARCH SIGNIFICANCE

The significance of this study lies in a non-destructive approach for identifying the fundamental frequencies of buildings through the combined application of HVSR, FSR, and RDM approaches. This integrated approach provides a comprehensive understanding of structural dynamic behavior and soil–structure interaction without the need for artificial excitation. In practical applications, the results can be applied for structural health monitoring and safety evaluation of existing buildings in earthquake-prone areas. Furthermore, this research also contributes to the development of a fast, economical, and reliable methodology for the dynamic analysis of buildings based on ambient vibration data.

3. MATERIALS AND METHODS

3.1 Research Location

The study investigated twelve (12) multi-story buildings in Aceh Province, Indonesia (Figure 1 and Table 1). These buildings have different functions, heights, and structural characteristics, which enable the present study to compare the dynamic behavior across representative low- to mid-rise structures.

3.2 Data Acquisition and Analysis

Ambient vibration measurements were conducted using a Raspberry Shake 3D triaxial seismometer equipped with three orthogonal 4.5 Hz velocity geophones.

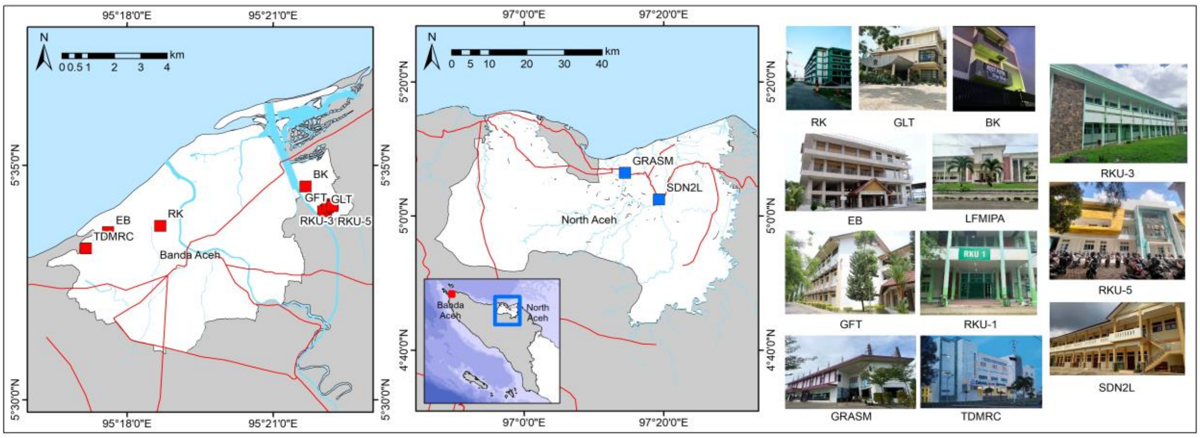

Fig.1 In the present study, a total of 12 buildings were investigated at two separated locations within Aceh Province, Indonesia. Ten buildings are located in the first study area of the city of Banda Aceh (red square), while the remaining two buildings are situated in the second study area of North Aceh District (blue square).

The manufacturer reported that the specifications of the geophone are as follows: a sensitivity of 3.60 x 10^8 counts/(m/s), 10% precision for V5+ units, a 144 dB digitiser dynamic range, and an effective complete-chain dynamic range of about 124 dB at 100 sps. In the data acquisition, the seismometer was placed on floor slabs, aligned with the principal structural axes, and recorded for at least 30 minutes at each observation level of the investigated building.

The recorded signals were converted into a compatible format and processed using Geopsy software. No additional manual detrending step was introduced beyond the standard software workflow used during analysis. To evaluate signal stationarity, the ambient vibration records were examined in multiple time windows. The stability of the dominant frequency was assessed from the variability of the HVSR response among accepted segments. Only windows showing consistent spectral characteristics were used for the final interpretation. During field acquisition, the anthropogenic activities at the surrounding measured locations were recorded, including nearby traffic, human activity, and building service noise where present. Any transient events, such as sudden footsteps, door slams, or short-duration local disturbances, were noted during field acquisition.

Table 1. Details location of the 12 buildings investigated in the present study

Building ID	Coordinates (Longitude, Latitude)	Remarks
RK	95.31126974, 5.561819288	5 story residential building
GFT	95.36798307, 5.567521127	3 story school building
GLT	95.36711379, 5.566958241	3 story laboratory building
RKU-1	95.37030706, 5.569497496	2 story school building
LFMIPA	95.36866053, 5.56834533	2 story laboratory building
RKU-3	95.37008417, 5.568949496	2 story school building
RKU-5	95.37020057, 5.56880974	2 story school building
BK	95.36098305, 5.575808388	3 story school building
EB	95.29343768, 5.55954724	3 story escape building
TDMRC	95.28578535, 5.553758015	3 story school building
GRASM	97.24039492, 5.107380101	2 story commercial building
SDN2L	97.32207553, 5.040785767	2 story school building

These disturbances were also checked visually on the time series recorded waveform and then excluded using the window-selection tool prior to further analysis. A frequency-domain band-pass filter of 1–6 Hz, together with a Tukey taper with a width (α/2) of 25%, was applied.

HVSR, FSR, and RDM were applied using the H/V, Spectrum, and Damping tools within the Geopsy package, respectively. For HVSR, the horizontal component was calculated from the quadratic mean of the E-W and N-S spectra. For RDM, free-decay signatures were obtained by conditional averaging using a positive-derivative zero-crossing trigger. HVSR peaks were interpreted as dominant resonance, FSR as floor amplification and structural frequency response, and RDM as a time-domain estimate of natural frequency and damping.

3.3 Theoretical Basis of Passive Seismic Frequency Identification

Under ambient excitation, the lateral response of a building can be idealized as an equivalent single-degree-of-freedom system, as formulated below.

$$m\, d^2u/dt^2 + c\, du/dt + ku = -ma_g(t) \quad (1)$$

where m, c, and k denote mass, damping, and lateral stiffness, consecutively. u is the relative displacement, and ag(t) is the ground acceleration. The undamped circular natural frequency, ω_n is formulated, as follows:

$$\omega_n = \sqrt{k/m} \quad (2)$$

The corresponding fundamental frequency, f_n formulated as Equation 3, below.

$$f_n = \omega_n/2\pi \quad (3)$$

Therefore, a reduction in effective stiffness directly causes a reduction in natural frequency.

For a soil layer of thickness *H* over a stiffer half-space, the approximate site fundamental frequency can be expressed as:

$$f_0 \approx V_s/4H \quad (4)$$

where *Vs* is the average shear-wave velocity of the soil layer. This relationship indicates that low-frequency peaks in ambient vibration records may be governed not only by structural resonance but also by local site effects and soil-structure interaction [9,11,19]. In the HVSR approach, the spectral ratio is written as:

$$HVSR(f) = H(f)/V(f) \quad (5)$$

$$H(f) = \sqrt{(S_{EW}(f)^2 + S_{NS}(f)^2)/2} \quad (6)$$

where S_{EW}, S_{NS}, and V are the Fourier amplitude spectra of the east-west, north-south, and vertical components, respectively. Peaks in the HVSR curve are commonly interpreted as dominant or fundamental resonance frequencies associated with site response or coupled soil-structure effects [1,4,7,19,20]. For floor spectral ratio analysis, the amplification at floor i is expressed as:

$$FSR_i(f) = A_i(f)/A_{ref}(f) \quad (7)$$

where $A_i(f)$ is the horizontal amplitude spectrum at floor i and $A_{ref}(f)$ is the corresponding spectrum at the reference level. Because the comparison is made between responses within the same structure, FSR is effective for identifying floor amplification and the fundamental lateral mode of the building [18,21,22].

In the random decrement method, the free-decay signature is obtained by averaging many short windows extracted from random vibration records:

$$R(\tau) = 1/N \sum_{i=1}^{N} x(t_i + \tau) \quad (8)$$

where $x(t_i)$ satisfies a selected trigger condition. The damping parameter can then be evaluated using the logarithmic decrement:

$$\delta = (1/n)\ ln(x_1/x_{(n+1)}) \quad (9)$$

The damping ratio is estimated as:

$$\xi = \delta/\sqrt{4\pi^2 + \delta^2)} \quad (10)$$

By suppressing uncorrelated noise while preserving coherent structural oscillation, RDM enables the estimation of natural frequency and damping ratio from ambient vibration data [18,22]

4. RESULTS AND DISCUSSION

4.1 Ambient Vibration Signal Quality and Measurement Stability

As aforementioned, signal quality was evaluated to ensure that the ambient vibration records adequately represented the dynamic response of the structures. Figure 2 shows the dominant-frequency distribution measured at the three-floor GFT building, with separate data clusters for the first, second, and third floors.

Generally, the dominant-frequency picks shift with floor level. The results of the present study suggest the frequency about 4.0-5.0 Hz for the first floor, 3.0-3.5 Hz for the second floor, and 2.5-3.0 Hz for the third floor. These results indicate height-dependent floor response under ambient excitation. Upper floors are more strongly governed by global first-mode lateral deformation and dynamic amplification, whereas lower floors may include higher-frequency local components and foundation-constrained response. Thus, the values should be interpreted as dominant floor-response peaks rather than independent natural frequencies for each floor [10,23].

As shown in Figure 2, limited temporal variability in the dominant-frequency estimation is presented in the selected observation windows. This pattern supports the temporal stability of the ambient vibration records and indicates that the data are suitable for subsequent frequency identification. The stability assessment should therefore be interpreted in terms of waveform continuity, spectral repeatability, and inter-channel coherence, rather than as a direct result of the top-floor frequency comparison alone. The absence of pronounced scatter also suggests that ambient vibration sources, such as wind, background ground motion, and low-level human activity, did not introduce substantial impulsive disturbances during the measurements. This interpretation is further supported by the spectral and coherence analyses between channels, which indicate phase consistency within the frequency range relevant to the structural response. These findings are in good agreement with Valla et al. [24], who identified amplitude and phase stability in the frequency domain as important indicators of signal quality for structural vibration monitoring. The increase in vibration amplitude toward upper floors is also consistent with dynamic amplification associated with the fundamental mode [25].

No significant anomalies were observed between recording intervals, as shown in Figure 2, indicating low instrumental noise and an adequate signal-to-noise ratio. The dataset was therefore suitable for HVSR, FSR, and RDM analyses. Overall, the floor-wise shift in dominant-frequency picks reflects modal participation and dynamic amplification along the building height. The consistent frequency distribution supports the use of the data for method comparison, while the interpretation of stiffness and amplification should still consider mode shape, mass distribution, boundary conditions, and foundation response.

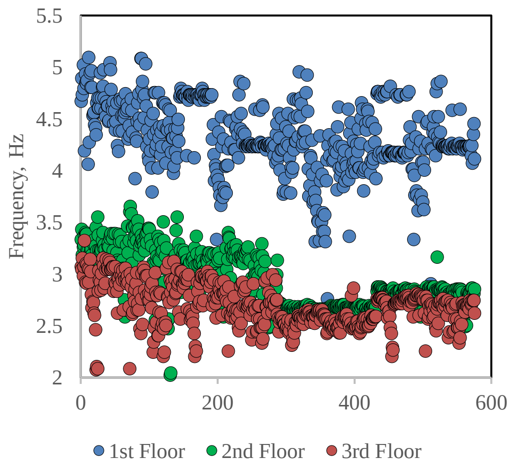

Fig. 2. Example of frequency stability analysis at each floor of the GFT building

4.2 Sensitivity of the Applied Approaches in Identifying Structural Frequency

Sensitivity analysis of the applied approaches was performed by comparing the dominant-frequency estimates of the structure obtained using three approaches of the horizontal-to-vertical spectral ratio (HVSR), floor spectral ratio (FSR), and random decrement method (RDM). As mentioned previously, all three approaches were applied to ambient vibration data recorded on each floor of the investigated buildings.

The data processing results show that the HVSR method produces lower dominant-frequency estimates than FSR and RDM. In the representative floor-by-floor examples, HVSR dominant-frequency peaks are concentrated at approximately 0.8-1.1 Hz, whereas the top-floor results, as summarized in Table 2, range from 0.88 to 2.44 Hz. These values are consistently lower than the paired FSR and RDM estimates, supporting the interpretation that HVSR is influenced by site-related resonance or coupled soil-structure response, rather than representing only the intrinsic lateral resonance of the building. Furthermore, HVSR is calculated from the ratio between horizontal and vertical components, the identified peak can remain sensitive to subsurface layering, impedance contrast, and foundation-soil interaction [11].

In contrast, the FSR method yields higher frequency estimates than HVSR. For the top floor, the FSR values, as shown in Table 2, range from 2.02 to 4.29 Hz across the E-W and N-S components. FSR compares the horizontal response of an upper floor with that of a reference level, this more directly emphasizes the relative lateral response of the structure. The directional comparison indicates that the E-W and N-S components are not always interchangeable. In the present study find that some buildings show small directional differences, others, including GFT, EB, RKU-3, RKU-5, and LFMIPA, exhibit more pronounced component-dependent variations. These differences may reflect plan stiffness asymmetry, mass distribution, boundary conditions, or directional variability in ambient excitation [26].

The RDM approach also produces higher frequency estimates than HVSR and is broadly comparable with FSR. On the top floor, the RDM values range from 2.43 to 4.19 Hz. The paired FSR-RDM differences are generally moderate, with an average absolute difference of approximately 0.15 Hz across the E-W and N-S components. In several cases, larger deviations occur, including GFT in the E-W component and GLT in the N-S component. Thus, the agreement between FSR and RDM should be interpreted as overall consistency rather than exact coincidence. By suppressing uncorrelated noise through ensemble averaging, RDM can isolate a stable free-decay signature and provide an independent estimate of the building's natural frequency under ambient excitation [27].

The overall comparison suggests that FSR and RDM are more appropriate than HVSR for estimating structural lateral natural frequencies from ambient floor records. HVSR remains valuable for identifying site-related or coupled soil-structure effects, but its lower peaks should not be interpreted as intrinsic structural frequencies without supporting geotechnical or free-field evidence. The floor-to-floor decrease observed in Figure 3 reflects modal distribution and dynamic amplification associated with the first vibration mode, whereas Table 2 confirms that, at the top floor, FSR and RDM systematically produce higher structural-frequency estimates than HVSR.

4.3 Comparison Between HVSR, FSR, and RDM

A comparison of dominant-frequency estimation results obtained using the horizontal-to-vertical spectral ratio (HVSR), floor spectral ratio (FSR), and random decrement method (RDM) reveals clear differences in the dominant frequency values measured at the top floor of each building. As shown in Table 2 and Figure 4, the HVSR estimates for the top floor range from 0.88 to 2.44 Hz, with the minimum value observed in SDN2L and the maximum value observed in TDMRC. In contrast, FSR and RDM produces higher estimates, with the combined range extending from 2.02 to 4.29 Hz across buildings and horizontal components. The lowest FSR/RDM value is the FSR E-W estimate for GFT (2.02 Hz), while the highest is the FSR N-S estimate for RKU-3 (4.29 Hz). These differences are unlikely to represent measurement error alone. This is likely reflecting the different physical quantities, signal components, and response mechanisms emphasized by each method.

The HVSR approach was originally developed to identify dominant site frequencies [4,17]. In building assessment, the HVSR dominant frequency peak may reflect a combination of local site resonance, vertical-component effects, and soil-structure interaction. Consequently, the frequency values derived from HVSR should not be interpreted automatically as intrinsic building frequencies [19,20,28]. The consistently lower HVSR values, as shown in Table 2, support this interpretation. In contrast, FSR analyzes the spectral ratio between a specific floor and a reference floor, typically the ground floor, thereby isolating the relative horizontal response between floors without directly incorporating vertical motion. FSR, therefore, focuses more strongly on the internal dynamic behavior of the structure governed by the interaction of mass, stiffness, and damping within structural elements. Operating in the frequency domain, this FSR approach can identify the fundamental lateral vibration mode, which is closely related to the building's global stiffness [8, 9, 21]. The higher frequency values obtained using FSR compared with HVSR in this study indicate that FSR is more sensitive to structural lateral response and less directly controlled by vertical-component or site-resonance effects.

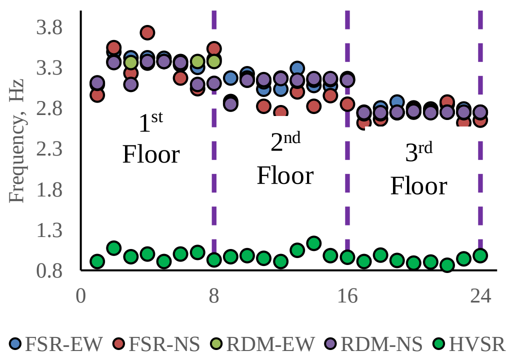

Fig. 3. Example of the sensitivity of the applied methods in identifying the structure's fundamental frequency (GLT building): (a) HVSR, (b) FSR, and (c) RDM

RDM estimates an approximate free-vibration response through time-domain random averaging, suppressing uncorrelated components and providing frequency estimates independent of spectral-ratio peaks.

Table 2. Comparison of structural frequencies on the top floor using each method

Building ID	Building Frequency (Hz)				
	FSR		RDM		HVSR
	E-W	N-S	E-W	N-S	
RK	2.60±0.07	2.43±0.05	2.56±0.08	2.55±0.07	2.07±0.01
GFT	2.02±0.02	2.62±0.03	2.48±0.01	2.49±0.01	1.00±0.04
GLT	3.09 ±0.04	2.96±0.08	3.10±0.08	3.37±0.07	0.95±0.04
GRASM	2.84±0.08	2.67±0.09	2.75±0.09	2.74±0.09	0.95±0.05
SDN2L	2.85±0.01	2.57±0.01	2.66±0.02	2.77±0.07	0.88±0.01
RKU-1	3.59±0.02	3.63±0.01	3.61±0.01	3.61±0.01	0.95±0.01
LFMIPA	3.45±0.02	3.04±0.01	3.33±0.02	3.28±0.02	1.06±0.01
RKU-3	3.79±0.02	4.29±0.09	4.09±0.09	4.19±0.08	1.03±0.01
RKU-5	3.52±0.02	3.03±0.01	3.42±0.09	3.23±0.08	1.00±0.01
BK	3.70±0.01	3.91±0.03	3.85±0.01	3.85±0.01	1.44±0.01
EB	2.31±0.02	2.88±0.02	2.43±0.01	2.63±0.02	2.09±0.01
TDMRC	3.64±0.01	3.86±0.03	3.80±0.01	3.80±0.06	2.44±0.01

The RDM values are generally consistent with FSR, with a mean absolute paired difference of about 0.15 Hz. A minor discrepancy is only of 0.46 Hz for GFT E-W and 0.41 Hz for GLT N-S. This show that component-dependent and building-specific effects remain important. Thus, FSR and RDM are mutually supportive rather than directly interchangeable [22].

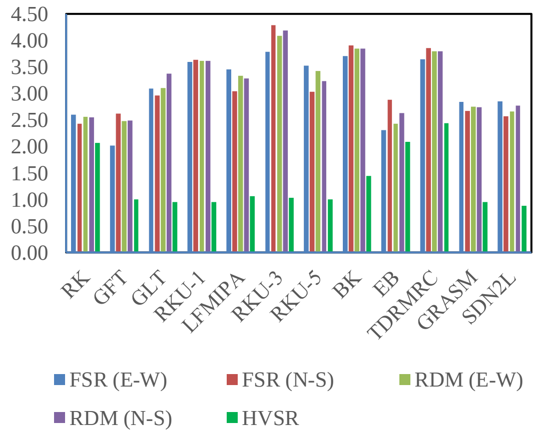

Fig. 4. Comparison of frequencies on the highest floor of each structure using the three approaches

HVSR is consistently lower than FSR and RDM. This pattern may indicate weaker impedance contrast, a stiffer foundation condition, or stronger coupling between site and structure, causing the dominant site-related peak to approach the building's lateral frequency. Such cases emphasize that HVSR should be interpreted together with structural and geotechnical context rather than as a stand-alone estimate of intrinsic structural frequency. It should also be noted that the low-frequency peaks identified in the HVSR results may not exclusively represent structural resonance but may reflect local site effects or coupled soil-structure interaction. This interpretation is consistent with the geological setting of Banda Aceh, where previous free-field HVSR inversion and subsurface characterization indicated site natural frequencies in the range of 0.74-1.94 Hz and generally low near-surface shear-wave velocity conditions, suggesting the presence of soft to medium soil layers with amplification potential [4].

5. CONCLUSION

Accurate identification of structural frequency is essential for seismic performance evaluation, retrofitting decisions, and disaster-mitigation planning. Based on the comparative analysis of three structural frequency identification approaches, i.e., the horizontal-to-vertical spectral ratio (HVSR), the floor spectral ratio (FSR), and the random decrement method (RDM), it was found that each method exhibits distinct sensitivities and characteristics in capturing the dynamic response of structures to ambient vibrations. The HVSR method yields lower frequency values because it predominantly reflects site response and the influence of soil conditions surrounding the foundation. In contrast, the FSR and RDM methods produce higher and more consistent frequency estimates that more accurately describe the intrinsic dynamic behavior of the structure.

This study has several limitations that should be acknowledged. First, ambient vibration measurements were conducted under natural excitation conditions that depend on environmental activities. Variations in vibration energy levels may affect the consistency of results across measurement sessions. Second, the number of sensors installed per floor was limited, which restricted the ability to fully capture the spatial distribution of structural response. Third, the analysis using FSR and RDM considered only horizontal components, excluding vertical motion. This suggests that potential effects of vertical coupling on vibration modes were not fully characterized. Fourth, nonlinear soil–structure interaction effects at large vibration amplitudes were not examined. Future work should complement the present framework with more detailed instrument and processing information, free-field site characterization, and uncertainty analysis for frequency and damping estimates so that inter-method comparisons can be reproduced more rigorously.

6. ACKNOWLEDGEMENTS

This research was funded by Universitas Syiah Kuala, Kementerian Pendidikan, Kebudayaan, Riset, dan Teknologi through PRUU-PD 2023 Grant No. 530/UN11.2.1/PT.01.03/PNBP/2023 dated 3 May 2023 and Penelitian Lektor Kepala 2023 Grant No. 148/UN11.2.1/PT.01.03/PNBP/2023 dated 3 May 2023.

7. REFERENCES

[1] Perret, D., Dietiker, B., Gravel, S.P., Fournier, T., and Pugin, A.J. Ambient Micro-Vibration Measurements in Geotechnical Engineering: A Practical Approach to the HVSR Method. Geological Survey of Canada, Open File 9200. 2024. https://doi.org/10.4095/p6qwj6n6fj

[2] Setiawan, B., Saidi, T., and Jaksa, M. Result of Site-Specific Ground Response Analysis. International Journal of GEOMATE. 2020 18(70), pp 9-15. https://doi.org/10.21660/2020.70.5530

[3] Setiawan, B., Jaksa, M., Griffith, M., and Love, D. Seismic site classification based on constrained modeling of measured HVSR curve in regolith sites. Soil Dynamics and Earthquake Engineering. 2018 110, pp 244-261. https://doi.org/10.1016/j.soildyn.2017.08.006

[4] Iskandar, J., Setiawan, B., Hasan, M., Achmad, A., and Yulianur, A. Shear Wave Velocity Model Using HVSR Inversion Beneath Banda Aceh City, Indonesia. 2025 29(133), pp 64-71. https://doi.org/10.21660/2025.133.5002

[5] Beskhyroun, S., Navabian, N., Wotherspoon, L., and Ma, Q. Dynamic behaviour of a 13-story reinforced concrete building under ambient vibration, forced vibration, and earthquake excitation. Journal of Building Engineering. 2020, 28(101066). https://doi.org/10.1016/j.jobe.2019.101066

[6] He, Y., Liu, Y., Wu, M., Fu, J., and He, Y. Amplitude dependence of natural frequency and damping ratio for 5 supertall buildings with moderate-to-strong typhoon-induced vibrations. Journal of Building Engineering. 2023 78(107589). https://doi.org/10.1016/j.jobe.2023.107589

[7] Mihaylov, D., Naggar, M. H.E., Dineva, S. Separation of High- and Low-Level Ambient

Noise for HVSR: Application in City Conditions for Greater Toronto Area. Bulletin of the Seismological Society of America. 2016 106(5), pp 2177-2184. https://doi.org/10.1785/0120150389

[8] Gosar, A. Site effects and soil-structure resonance study in the Kobarid basin (NW Slovenia) using microtremors. Natural Hazards and Earth System Sciences. 2010 10(4), pp 761-772. https://doi.org/10.5194/nhess-10-761-2010

[9] Gosar, A., Roser, J., Motnikar, B.S., and Zupancic, P. Microtremor study of site effects and soil-structure resonance in the city of Ljubljana (central Slovenia). Bulletin of Earthquake Engineering. 2010 8, pp 571-592. https://doi.org/10.1007/s10518-009-9113-x

[10] Luzi, G., Crosetto, M., and Fernandez, E. Radar Interferometry for Monitoring the Vibration Characteristics of Buildings and Civil Structures: Recent Case Studies in Spain. Sensors. 2017 17(4). https://doi.org/10.3390/s17040669

[11] Mucciarelli, M., Masi, A., Gallipoli, M.R., Harabaglia, P., Vona, M., Ponzo, F., and Dolce, M. Analysis of RC Building Dynamic Response and Soil-Building Resonance Based on Data Recorded during a Damaging Earthquake (Molise, Italy, 2002). Bulletin of the Seismological Society of America. 2004 94(5), pp 1943-1953. https://doi.org/10.1785/012003186

[12] Fathani, T.F., and Wilopo, W. Seismic Microzonation Studies Considering Local Site Effects for Yogyakarta City, Indonesia. International Journal of GEOMATE. 2017 12(32), pp 152-160. http://doi.org/10.21660/2017.32.63655

[13] Nishimura, I., Noguchi, T., and Kagawa, T. Estimation of Subsurface Structures and Ground Motion Characteristics in the Areas Damaged in the 2016 Central Tottori Prefecture Earthquake in Japan. International Journal of GEOMATE. 2021 20(82), pp 15-21. https://doi.org/10.21660/2021.82.Gx185

[14] Noguchi, T., Nishimura, I., and Kagawa, T. Estimation of Subsurface Structure of Landslide Area Based on Microtremor Observation in the Hojoshima, Nawashiro and Amedaki Area, Tottori, Japan. International Journal of GEOMATE. 2021 21(88), pp 48-53. https://doi.org/10.21660/2021.88.gxi279

[15] Wibowo, N.B., Fathani, T.F., Pramumijoyo, S., and Marliyani, G.I. Microzonation of Seismic Parameters in Geological Formation Units Along the Opak River Using Microtremor Measurements. International Journal of GEOMATE. 2023 25(110), pp 208-219. https://doi.org/10.21660/2023.110.4017

[16] Siadari, D.A.D., Wilopo, W., and Fathani, T.F. Seismic Microzonation Studies in Jogja-Bawen Toll Road, Magelang Regency, Indonesia. International Journal of GEOMATE. 2023 25(110), pp 176-183. https://doi.org/10.21660/2023.110.4020

[17] Setiawan, B., Juellyan, J., Al-Huda, N., and Yulianur, A. Sub-surface shear wave velocity models developed based on a combined in-situ measurement of quasi-static cone penetration test (q-CPT) and microtremor datasets. Data in Brief. 2024 54(110501). https://doi.org/10.1016/j.dib.2024.110501

[18] Jahangiri, M., Hadianfard, M. A., and Shojaei, S. Evaluation of the frequency, damping, and vulnerability variations of masonry structures during the construction process using seismic response acquisition. Measurement. 2024 237(115201). https://doi.org/10.1016/j.measurement.2024.115201

[19] Nakamura, Y. Seismic Vulnerability Indices for Ground and Structures using Microtremor. World Congress on Railway Research, Florence, 1997.

[20] Krylov, A.A., Kulikov, M.E., Kovachev, S.A., Medvedev, I.P., Lobkovsky, L.I., and Semiletov, I.P. Peculiarities of the HVSR Method Application to Seismic Records Obtained by Ocean-Bottom Seismographs in the Arctic. Applied Sciences. 2022 12(19). https://doi.org/10.3390/app12199576

[21] Ates, E., and Uyanik, O. Comparison of soil-structure interaction obtained from spectral ratio methods applied to earthquake and microtremor records. Journal of Applied Geophysics. 2025 234(105645). https://doi.org/10.1016/j.jappgeo.2025.105645

[22] Jahangiri, M., Hadianfard, M., and Shojaei, S. Microtremor measurements for assessing the influences of non-structural components on the modal properties and vulnerability of steel structures. Measurement. 2022 201(111750). https://doi.org/10.1016/j.measurement.2022.111750

[23] Pirrotta, C., Gueli, A.M., Trigona, C., and Imposa, S. Coherence Analysis for Vibration Monitoring Under High Variability Conditions: Constraints for Cultural Heritage Preventive Conservation. Journal of Sensor and Actuator

Networks. 2025 14(2). https://doi.org/10.3390/jsan14020045
[24] Valla, M., Gueguen, P., Augere, B., Goular, D., and Perrault, M. Remote Modal Study of Reinforced Concrete Buildings Using a Multipath Lidar Vibrometer. Journal of Structural Engineering. 2014 141(1). https://doi.org/10.1061/(ASCE)ST.1943-541X.0001087
[25] Muhammad, Z., Reynolds, P., Avci, O., and Hussein, M. Review of Pedestrian Load Models for Vibration Serviceability Assessment of Floor Structures. Vibration. 2018 2(1), pp 1-24. https://doi.org/10.3390/vibration2010001
[26] Pashova, L., Oynakov, E., Paskaleva, I., and Ivanov, R. Seismic Response Analysis of a Six-Story Building in Sofia Using Accelerograms from the 2012 Mw5.6 Pernik Earthquake. Applied Sciences. 2025 15(15). https://doi.org/10.3390/app15158385
[27] Jahangiri, M., Hadianfard, M. A., and Rabiee, R. Seismic pathology and vulnerability assessment of historical masonry buildings implementing supervised ambient vibrations. Journal of Building Pathology and Rehabilitation. 2026 11(32). https://doi.org/10.1007/s41024-025-00708-3
[28] Kuria, K.K., and Brassai, O.K.K. Nonlinear Static Analysis for Seismic Evaluation of Existing RC Hospital Building. Applied Sciences. 2023 13(21). https://doi.org/10.3390/app132111626