IJESKA contribution to science

International Journal of Earth Sciences Knowledge and Applications

journal homepage: http://www.ijeska.com/index.php/ijeska

e-ISSN: 2687-5993

Research Article https://doi.org/10.5281/zenodo.22170483

Investigation of Soil Dominant Frequency using Single-Station Microtremor Method: A Case Study for Western Part of Atatürk University Campus, Erzurum (NE Türkiye)

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INFORMATION

Article history
Received 15 June 2026
Accepted 26 August 2026
Published 31 August 2026

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How cite
Güzelhan, Ü.N., Kalkan, E., Özer, Ç., 2026. Investigation of Soil Dominant Frequency using Single-Station Microtremor Method: A Case Study for Western Part of Atatürk University Campus, Erzurum (NE Türkiye). *International Journal of Earth Sciences Knowledge and Applications* 8 (2), 291-305. https://doi.org/10.5281/zenodo.22170483.

Abstract
Erzurum, located in northeastern Anatolia, is one of Türkiye's most seismically active provinces. The city is situated at the northern end of the tectonically controlled Karasu Basin, and its urbanization is currently progressing towards the basin center. The basin fill consists mostly of volcanic-origin clay, silt, sand, gravel, and blocks, with grain sizes gradually varying from the basin edges to the center. These sediments are expected to be susceptible to local site effects during strong ground motions. Therefore, determining the soil dominant frequency (f) is important, especially for areas with high residential development potential. In this context, a microtremor investigation was conducted at 78 points in the western part of the Atatürk University Campus in Erzurum (Northeast Turkey) using the Horizontal-Vertical Spectral Ratio (HVSR) method. While the soil dominant frequencies were mostly below 1 Hz, local values reached up to 15.4 Hz. Significant H/V amplitude (A) values and low f values were detected in the study area, which is located on alluvial fan deposits. The 0.12-1 Hz range corresponds to relatively long field periods and may be significant for structures whose natural periods overlap with this range. However, structural resonance cannot be assessed solely from the soil dominant frequency and also depends on the structural system and its dynamic characteristics. If this area is opened to construction in the future, a combined assessment of both building and soil-dominant frequencies is crucial. Furthermore, the findings of this passive-source study should be further validated with complementary active-source geophysical investigations.

Keywords
Erzurum, Karasu Basin, Microtremor, Soil Dominant Frequency, Site Effect

1. Introduction

The Alpine-Himalayan Seismic Belt is one of the world's most active tectonic and seismic regions (Trifonov and Sokolov, 2014). This belt is under the influence of intense tectonic deformation processes resulting from the convergence of the African, Arabian, and Eurasian plates (McKenzie, 1978). Ongoing plate movements have produced compressional, folding, thrust, and strike-slip faulting in the region, and the elastic stress that builds up is periodically released as large, destructive earthquakes. Türkiye lies within this belt and is among the countries where active tectonism is most clearly observed (Huang et al., 2002; Emre et al., 2018). The North Anatolian Fault Zone (NAFZ), the East Anatolian Fault Zone (EAFZ), and the West Anatolian Graben System (WAGS) are the main sources of the country's high earthquake risk (Hubert-Ferrari et al., 2002;

Erdik et al., 2004; Duman and Emre, 2013; Dogru et al., 2018; Emre et al., 2018; Akbayram et al., 2023).

Geologically young and fractured, the country is under constant plate-driven deformation, which puts it among the regions with the highest earthquake risk in the world. Based on Türkiye's tectonic structure and regional deformation, four main neotectonic zones have been identified: the East Anatolian Compression Province, the North Anatolian Province, the Central Anatolian Plain Province, and the West Anatolian Extension Province (Sengor, 1979; Reilinger et al., 1997; Bozkurt, 2001; Allen et al., 2004; Anadolu and Kalyoncuoglu, 2010).

Numerous microzonation studies have been conducted in urban development areas using various geophysical methods to characterize local site conditions and assess seismic hazards (Akkaya and Ozvan, 2019; Keskinsezer and Dag, 2019; Caielli et al., 2020; Akbayram et al., 2022; Bayrak, 2022; Fadli et al., 2023; Sarac and Ozer, 2024; Karsli and Bayrak 2024; Sarigul and Bayrak, 2025; Aydin et al., 2025). The primary aim of these studies is to understand the effect of local geological and geotechnical conditions on seismic wave propagation and site effect response characteristics using passive sources. Studies determining soil dominant frequency provide important information for evaluating the potential for soil-structure resonance. The resonance may occur when the soil dominant frequency (f) coincides with the natural frequency of a structure during a seismic event. This phenomenon can significantly amplify ground motion, leading to serious structural damage or even collapse. Therefore, determining the f or period (1/f) value and site effect is crucial during the planning and development of new settlement areas; the natural frequencies of existing structures should also be evaluated for effective seismic risk assessment (Putti and Satyam, 2020; Beker Usta and Sayil, 2024).

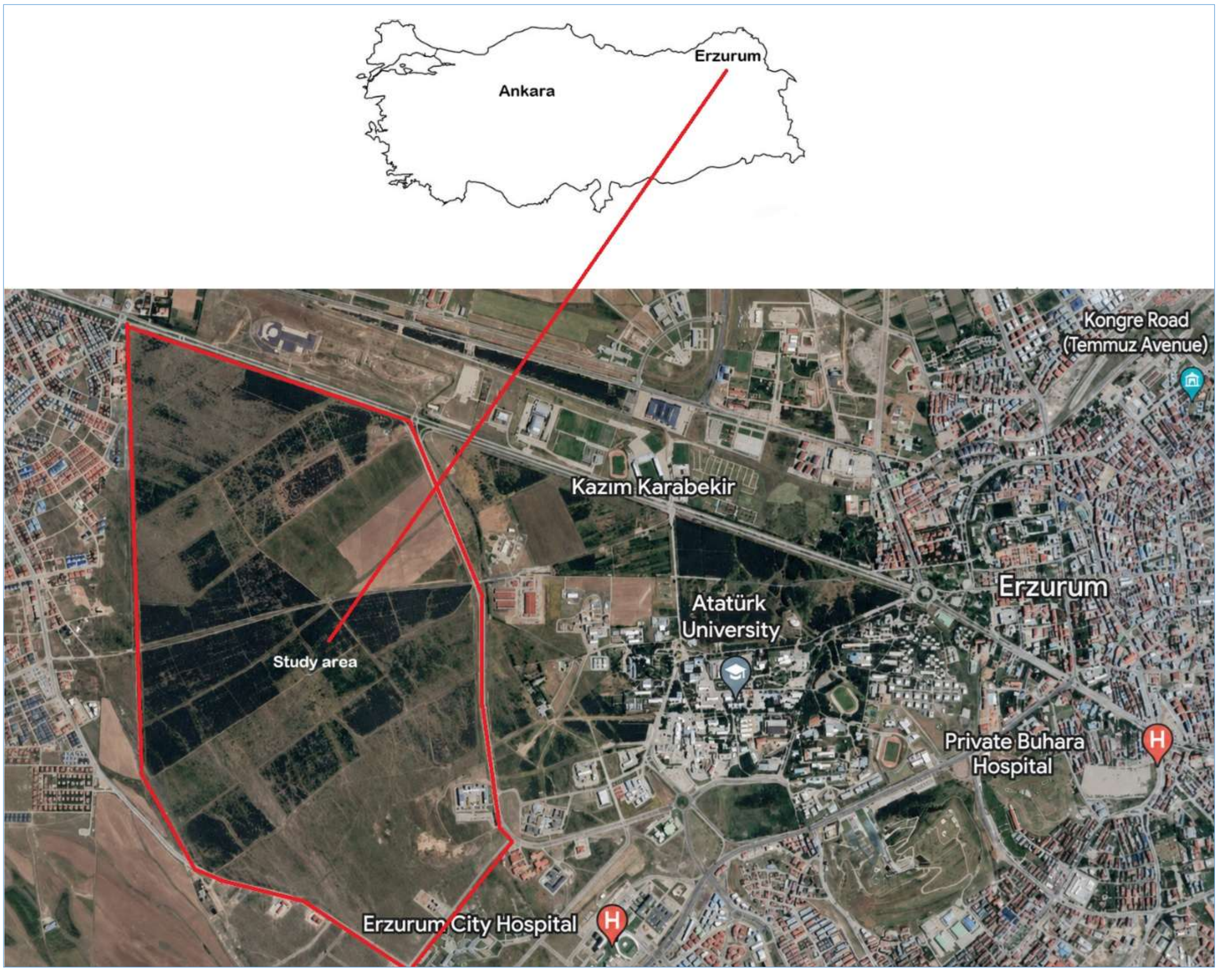

Fig. 1. Google Earth image of western part of Atatürk University Campus, NE Türkiye

Microtremor measurements are widely used in different regions of the world to estimate site effects and characterize local soil conditions (Nakamura, 1989; Bonilla et al., 1997; Lermo and Chavez-Garcia, 1993; 1994; Ibs-von Seht and Wohlenberg, 1999; Ozcan, 2013; Nakamura, 2019; Akbayram et al., 2022). Microtremors are ambient ground vibrations produced from natural or human-induced sources. These low-amplitude vibrations provide valuable information about subsurface geological structures and dynamic soil properties using the Horizontal-to-Vertical Spectral Ratio (HVSR) method. Nakamura (1989) demonstrated that microtremor measurements can be effectively used to reliably estimate the soil dominant frequency and H/V amplitude behavior of soil deposits. For these reasons, the microtremor method has become one of the most widely applied and cost-effective techniques for seismic microzoning and field response investigations (Nakamura, 2019).

This study, based on seismic activity affecting Erzurum and its surroundings, aims to highlight the importance of determining the dynamic parameters of soils in structural design studies in the selection of new settlement areas. The study area encompasses the western part of the Atatürk University campus and is surrounded by residential areas. This currently undeveloped area may be considered for future engineering development. The goal was to determine the soil dominant frequency and the H/V amplitude, which will provide important geotechnical data for future structures. Microtremor measurements were taken at 78 points within the scope of the field study. The findings obtained were evaluated, and the distributions of the soil dominant frequency for the study area were analyzed.

2. Material and Methods

2.1. Study Area

The study area, located in the western part of the Atatürk University campus, is situated within the Erzurum pull-apart basin in the NE Türkiye (Kocyigit and Canoglu, 2017). Currently devoid of any engineering structures and retaining its undeveloped characteristics, the study area is bordered by the Atatürk University main campus to the east and the Dadaşkent Urban Settlement Area to the west (Fig. 1). The investigation area, whose surrounding morphology is entirely encircled by intense urban development, possesses logistical and strategic significance at both macro- and micro-location scales.

Also, the study area has a potential for future urban development. Considering both the substantial structural development potential of the region and the seismic vulnerability of the local soils, this field investigation was planned and conducted.

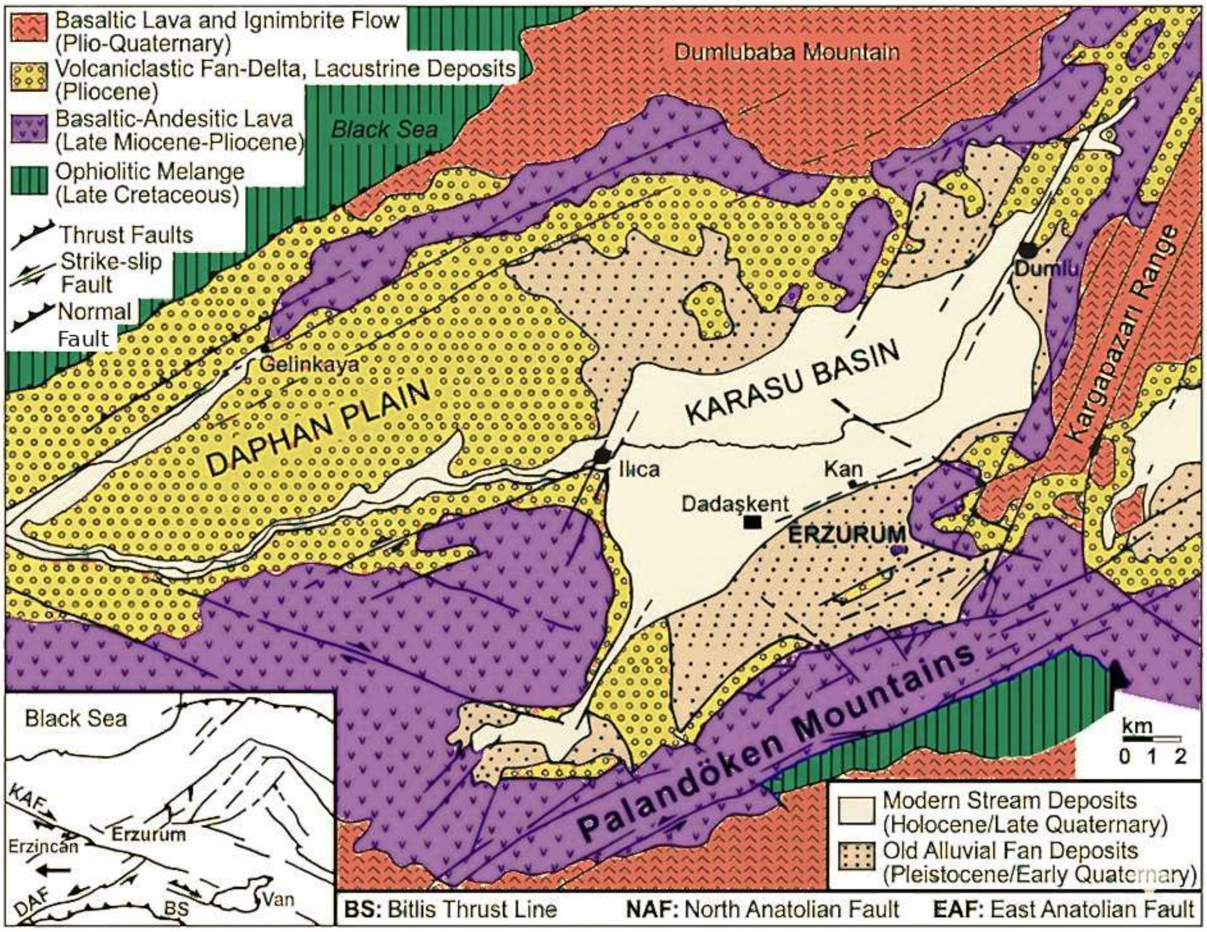

Fig. 2. The geological map of Karasu Basin and its surroundings (modified after Peynirci et al., 2010; Akbas et al., 2011). Tectonic units have been simplified from Emre et al. (2013; 2018)

The oldest geological unit exposed in the study area is the Anatolian Ophiolitic Melange. This unit, formed during the Late Cretaceous, represents the basement rocks of the region. During the tectonic evolution of the Anatolian Plate, particularly under the compressional tectonic regime associated with the closure of the Tethys Ocean, ophiolitic rock assemblages were emplaced over extensive areas. Compression-related tectonic activity lasting until the end of the Miocene caused the Anatolian Ophiolitic Melange to become widely exposed, and it now constitutes the principal geological basement of the region (Sengor and Yilmaz, 1981; Goncuoglu et al., 1997; Bozkurt, 2001; Tavlasoglu, 2021). Late Miocene-Pliocene calc-alkaline volcanic rocks and Pliocene-Quaternary alkaline volcanic rocks constitute the dominant geological units of the region. The calc-alkaline volcanic rocks are represented by andesitic, dacitic, and rhyolitic lava flows together with associated pyroclastic deposits. In contrast, the alkaline volcanic rocks form the surface cover of elevated plateau plains such as the Kargapazari Plateau and Gacarti Mountain. The lower volcanic units comprise domes, stratovolcanoes, and lava flows, whereas the upper units are characterized by sheet-like lava flows and monogenetic volcanic cones. The upper volcanic succession includes calc-alkaline and andesitic-dacitic to rhyolitic-basaltic sequences, accompanied by acidic volcanic products such as perlite, pumice, various colored scoria, rhyolites, and obsidian flows (Bayraktutan and Villa, 1986; Bayraktutan et al., 1996).

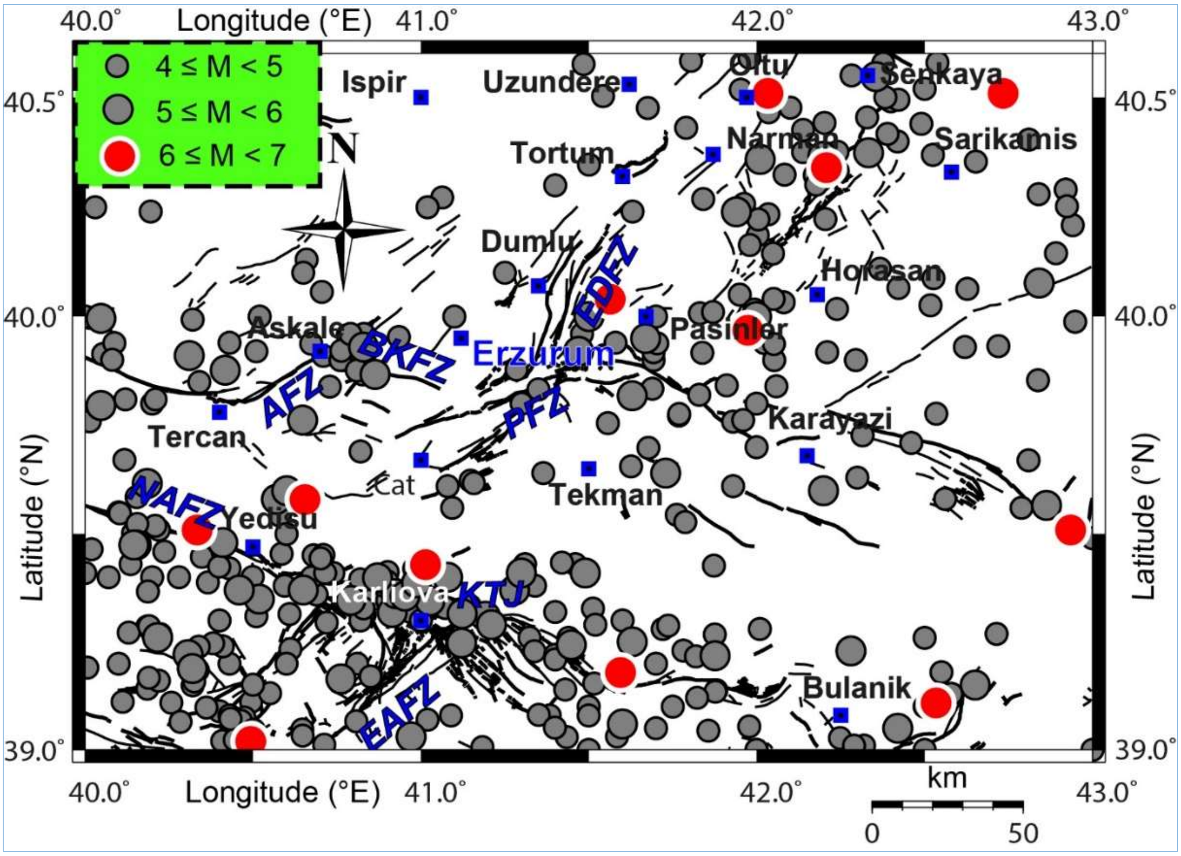

Fig. 3. Distribution of epicenters of earthquakes (M ≥ 4.0) recorded in Erzurum and its surrounding areas between 1900 and 2020 (modified after Bayrak et al. 2020). (AFZ Askale Fault Zone, BKFZ Baskoy-Kandilli Fault Zone, EAFZ East Anatolian Fault Zone, EDFZ Erzurum-Dumlu fault zone, PFZ Palandoken Fault Zone, KTJ Karliova triple junction, NAFZ North Anatolian Fault Zone).

Fig. 4. Microtremor measurement system (GURALP broadband CMG-6TD)

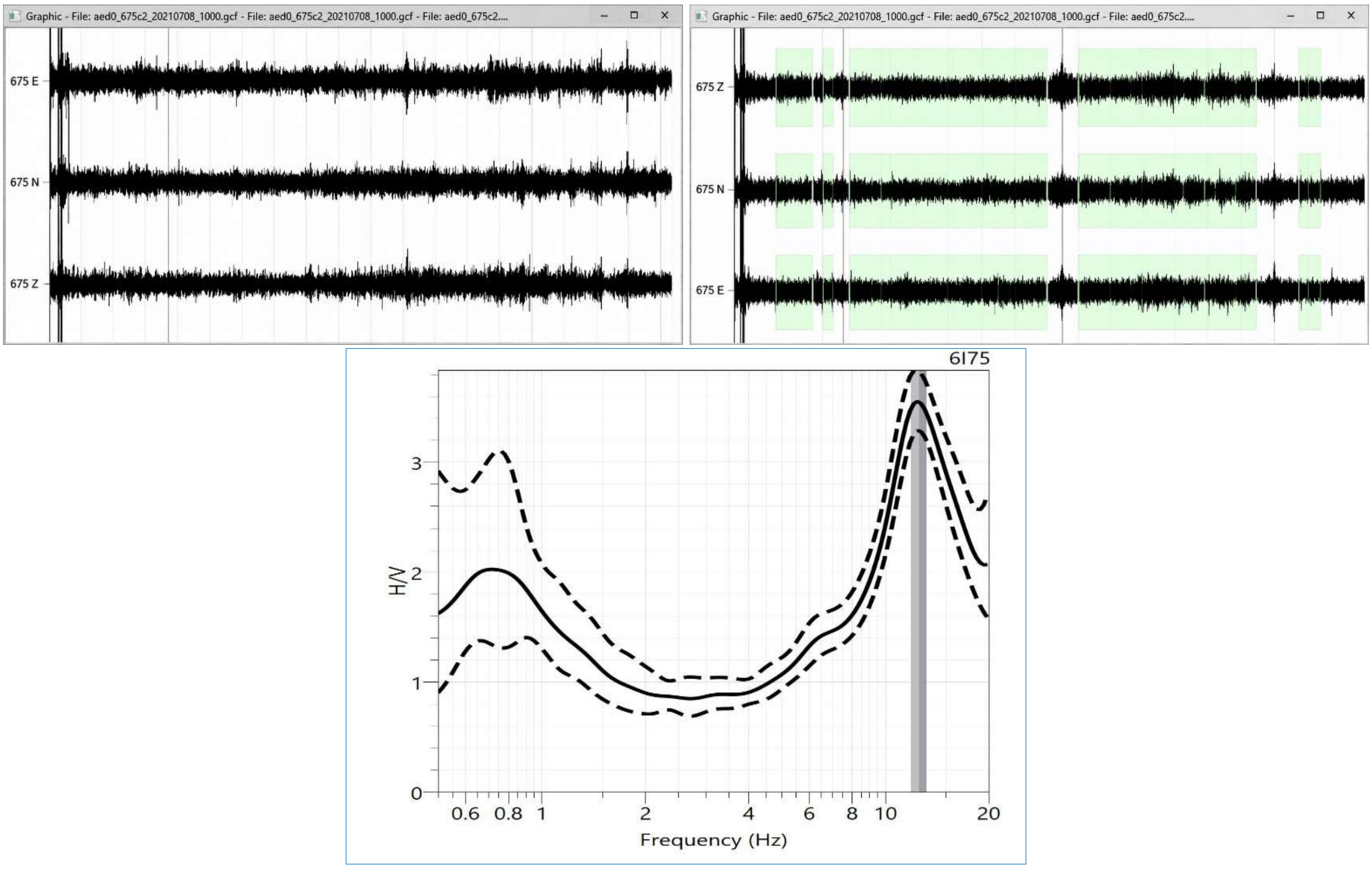

Fig. 5. Microtremor data evaluation using the HVSR method (analysis stages): a) Raw passive seismic data, b) window selection phase, c) Geopsy evaluation output

The Gelinkaya Formation, dating back to the Pliocene period, reflects the early seismotectonic and sedimentary evolution of Erzurum and its surroundings. The Pliocene-aged Gelinkaya Formation unconformably overlies the Late Miocene-Pliocene volcanic rocks and crops out along the margins of the Karasu Basin. First described by Arpat (1965), the formation consists of an alternation of gray-colored conglomerate, sandstone, claystone, and marl interbedded with tuffaceous layers. This formation contains Pontian lacustrine limestones that begin with an angular unconformity over Late Miocene-Pliocene volcanic rocks and contain pyroclastic interbeds in their upper levels.

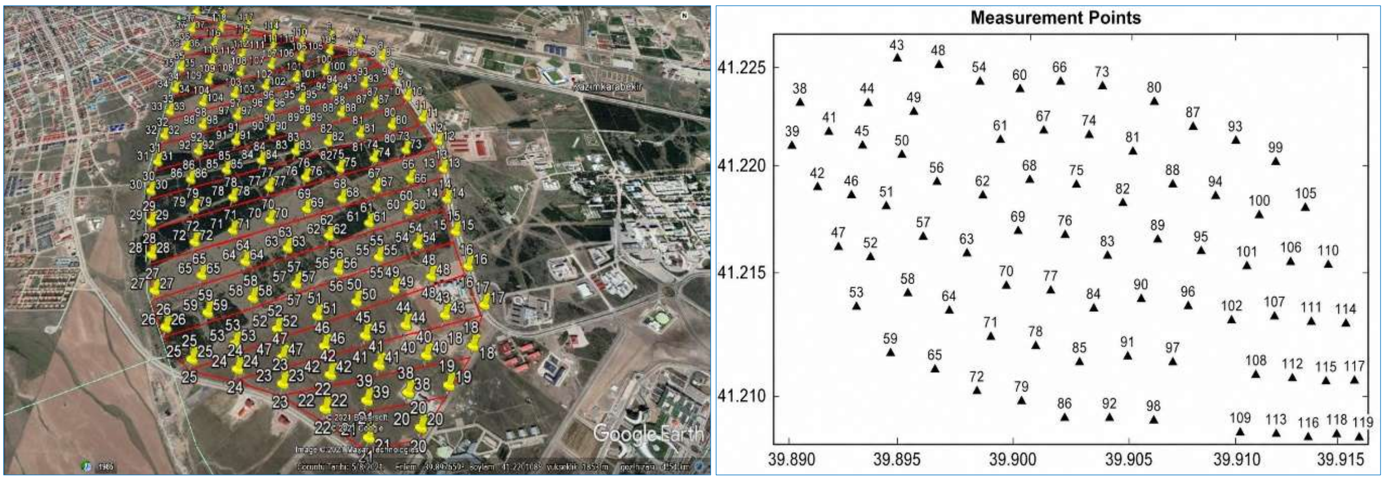

Fig. 6. Microtremor measurement points in the western part of Atatürk University Campus: (a) Designed measurement locations and (b) successfully measured points.

Gelinkaya Formation, exposed along the basin margins, exhibits a range of dynamic facies formations varying from alluvial fans, fan deltas, river channels, sand plains, and arid lake mud-sand plains to central shallow lacustrine environments. It was uplifted under the dominant compressional neotectonic regime in the region and subjected to strong seismotectonic deformation (Barka and Bayraktutan, 1985; Bayraktutan et al., 1996; Timur, 2000; Peynirci et al., 2010; Celik et al., 2021).

Türkiye has experienced numerous devastating earthquakes throughout both historical and instrumental measurement periods (Yalcin et al. 2013; AFAD, 2026), and due to its complex geological and tectonic structure (Akbas et al., 2011; Emre et al., 2013; Emre et al., 2018), the probability of similar magnitude earthquakes occurring in the future is quite high. The Karlıova Triple Junction (KTJ) is located relatively close to the city center of Erzurum, and major earthquakes occurring on either of these fault systems have the potential to significantly affect Erzurum and surrounding settlements. The Karasu Basin and the city of Erzurum, which developed within this basin, are located relatively close to the Karlıova (Bingöl) triple junction, where the North Anatolian Fault Zone (NAFZ) and the East Anatolian Fault Zone (EAFZ), two of the most active and seismically significant tectonic structures in Türkiye, converge (Fig. 3). This strategic location renders Erzurum and its surroundings one of the most significant seismotectonic zones of influence in Eastern Anatolia. Historical and instrumental earthquake records reveal that the active fault systems around Karliova exhibit high seismic activity (Akbayram et al., 2023) and can generate destructive earthquakes.

Particularly, major earthquakes that may occur along the segments of the NAFZ and EAFZ around Karliova have the potential to cause strong ground motions in the Erzurum city center and surrounding residential areas due to their proximity to the source zone.

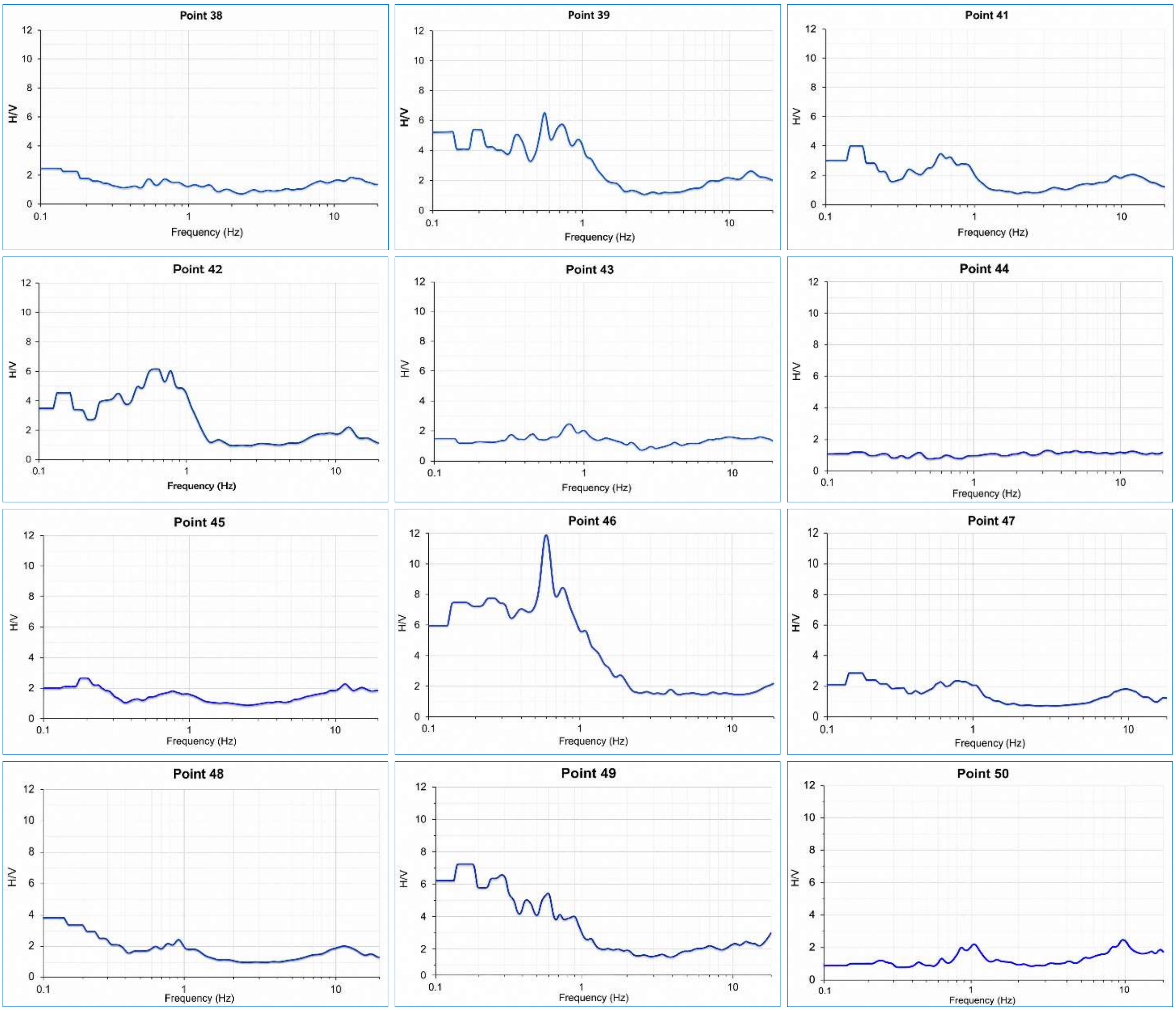

Fig. 7. Microtremor measurement results (H/V-frequency graphs) for points: 38-39, 41-50

Located on the Karasu Basin, which developed as a result of tectonic activity, the study area is under the control of the fault systems surrounding the Karasu Basin. The fault systems surrounding the Karasu Basin are shown in Fig. 2.

The city center of Erzurum is located on the southeastern edge of the Karasu Basin, and the city's new residential areas are developing towards the center of the Karasu Basin. Surrounded by many active tectonic fault systems, Erzurum and its surroundings have the potential for an earthquake with a magnitude between 6 and 7 every 30 years (Fig. 2.), according to statistical data (Yarbasi and Kalkan, 2009). The pull-apart Karasu Basin is under the influence of compressional tectonics that began in the Quaternary period. The Erzurum-Dumlu Fault Zone (EDFZ) is located on the east-southeast side of the basin. This left-lateral strike-slip fault zone is approximately 20 km wide and 150 km long. The fault zone in the south of the basin is the Palandoken Fault Zone (PFZ). The Askale Fault Zone (AFZ) and the Baskoy-Kandilli Fault Zone (BKFZ), which are strike-slip fault zones, are in the North-Northwest of the basin (Bayraktutan et al., 1996; Peynirci et al., 2010; Kocyigit and Canoglu, 2017; Ozer, 2019)

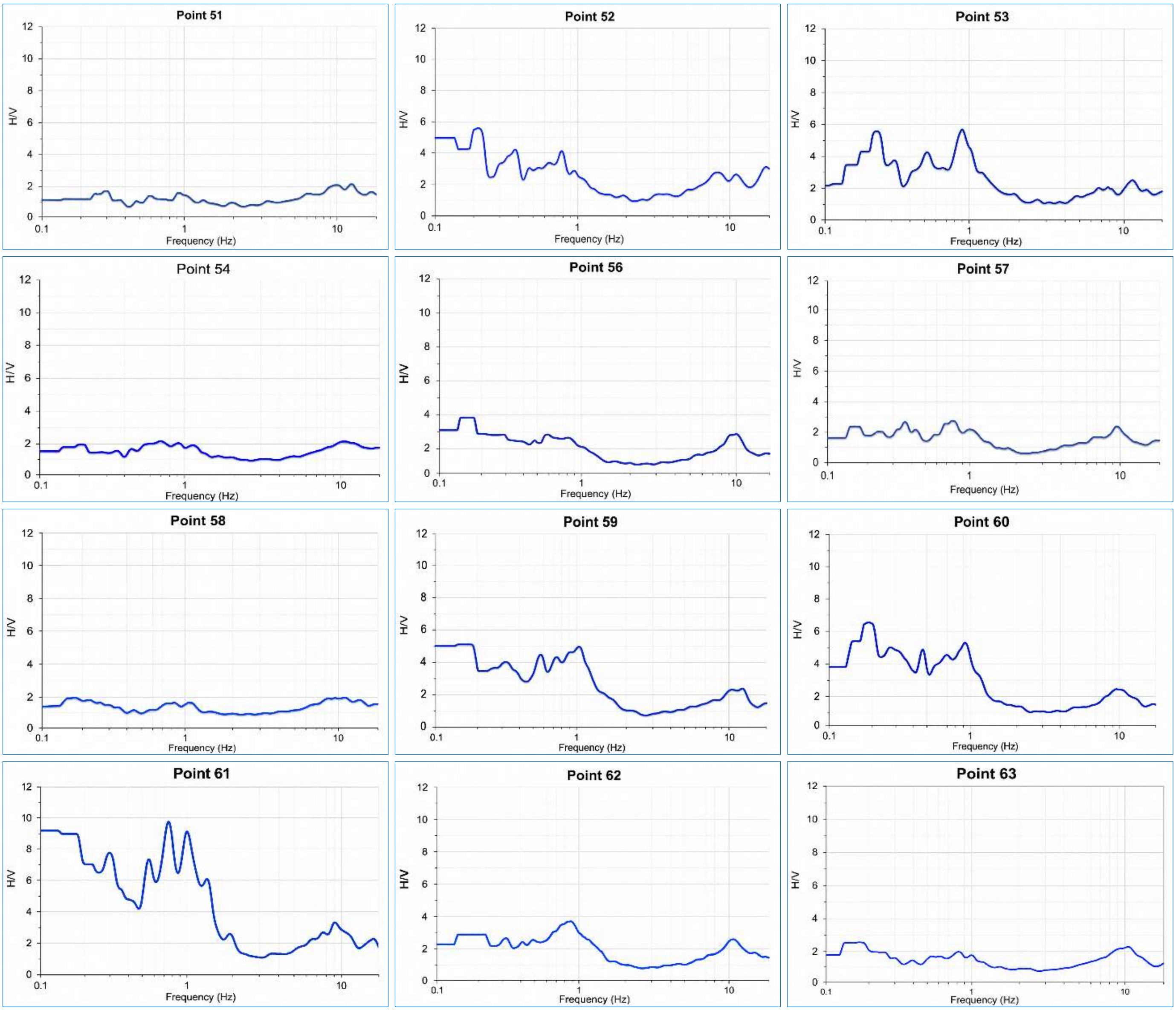

Fig. 8. Microtremor measurement results (H/V-frequency graphs) for points: 51-54 and 56-63

2.3. Data and Analysis

Elastic waves generated by a seismic source propagate through the heterogeneous Earth's crust, traversing both high-rigidity bedrock formations and unconsolidated sedimentary layers characterized by lower shear-wave velocities (*Vs*) relative to the underlying bedrock (Yalcinkaya, 2010). The duration and characteristics of seismic vibrations generated at the ground surface depend dynamically on several factors, including earthquake magnitude, source-to-site distance, and local site conditions. Seismic wave amplitude generally stays low in competent rock with high elastic moduli, while site effects can develop in alluvial and weakly consolidated deposits with poor geotechnical properties (Beker, 2011; Ates, 2021). This can be quantified empirically using on microtremor or earthquake recordings, such as the Horizontal-to-Vertical Spectral Ratio (HVSR) method (Nakamura, 1989; Lermo and Chavez-Garcia, 1993; Nakamura, 2019).

Microtremor measurements were carried out within the study area to investigate the local soil conditions. The measurement points were selected to represent the entire study area and to reflect the local soil characteristics in the most effective manner. Microtremor data were obtained using a portable broadband seismometer with a three-component digital output (Guralp Systems CMG-6TD). The seismometer and the measurement setup used in the study are presented in Fig. 4.

To ensure reliable and representative recording of ambient vibrations, data were collected for at least 30 minutes at each measurement point, and recordings were performed at a sampling frequency of 100 Hz. The microtremor records obtained were processed and analyzed using the Geopsy software package (Wathelet et al., 2020) to determine the dynamic properties of the local soil. Frequency-domain analyses were performed during the data processing stage, and the Horizontal-to-Vertical Spectral Ratio (HVSR) method (Nakamura, 2019) was applied to determine the soil dominant frequency and H/V peak characteristics of the soil.

Passive recordings were analyzed by dividing them into 20-second time windows, and Fourier amplitude spectra were calculated for the selected windows. A Butterworth band-pass filter was applied to the recordings in the range of 0.05-20 Hz, and the resulting Fourier spectra were smoothed using the Konno-Ohmachi method. Then, horizontal components were ratioed to the vertical component, and H/V spectral ratios were obtained.

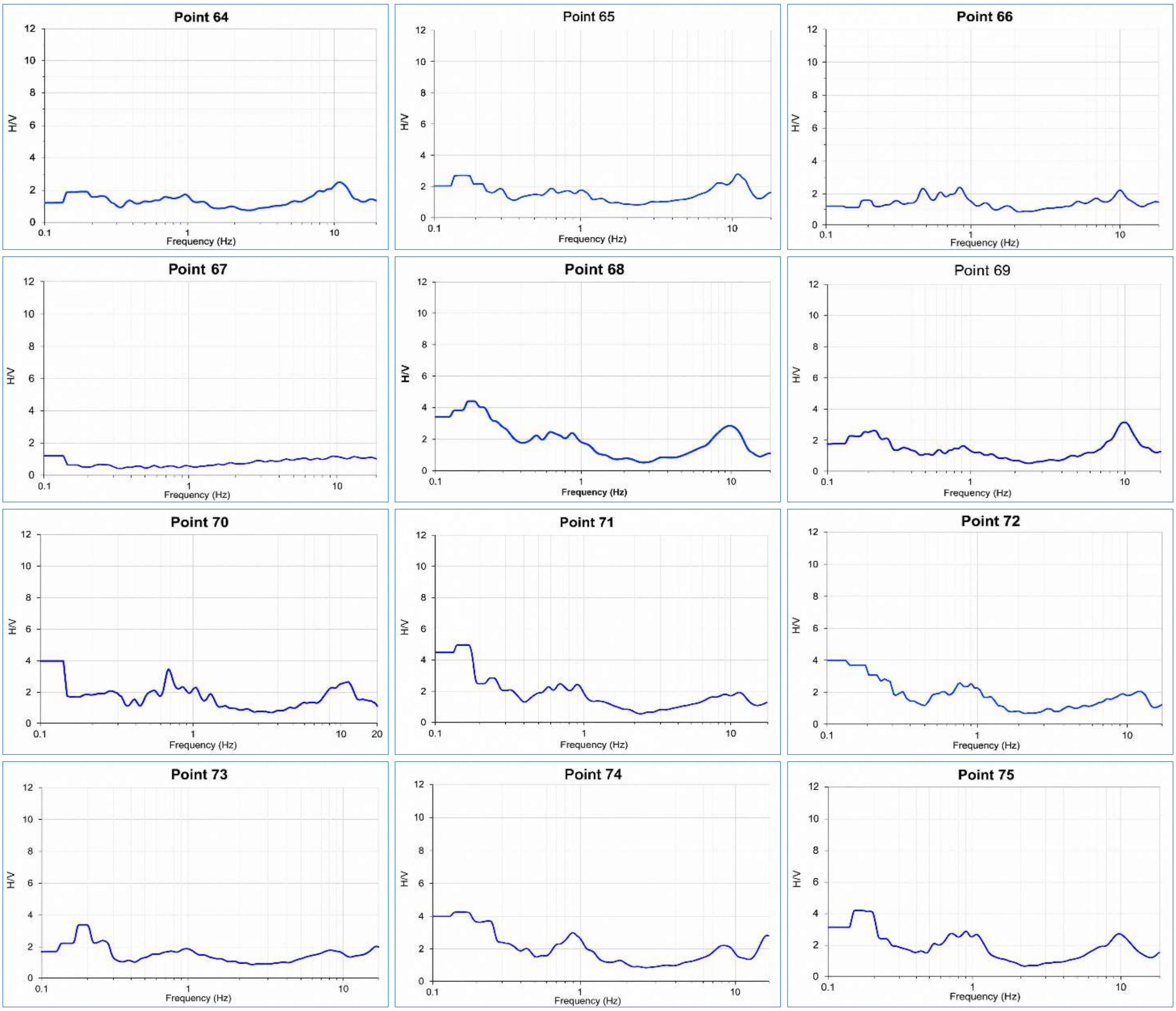

Fig. 9. Microtremor measurement results (H/V-frequency graphs) for points: 64-75

Using the resulting H/V curves, the soil dominant frequency was determined for each measurement point. Recordings with insufficient data quality or signal-to-noise characteristics were excluded from the final evaluation. A sample of the raw microtremor data, the window selection, and the Geopsy analysis output are presented in Fig. 5. Through these analyses, local soil conditions, dynamic behavior characteristics, and potential site effects in the study area were evaluated.

3. Results

A spatial distribution geometry at intervals of 250 meters (Fig. 6) was designed to investigate the soil dominant frequency (f) and H/V amplitude (A) values in the study area located in the western part of the Atatürk University campus; NE Türkiye. The Nakamura method (Nakamura, 1989) was used to investigate the soil conditions of the study area. Prior to the measurements, 119 points were identified, and microtremor measurements were designed at these points. However, only 78 points with sufficient signal-to-noise ratios were considered. During the measurement process, some of the identified points were physically unsuitable, and measurements could not be taken at these points; therefore, these points were excluded from the evaluation. The study continued with measurements taken from the remaining points.

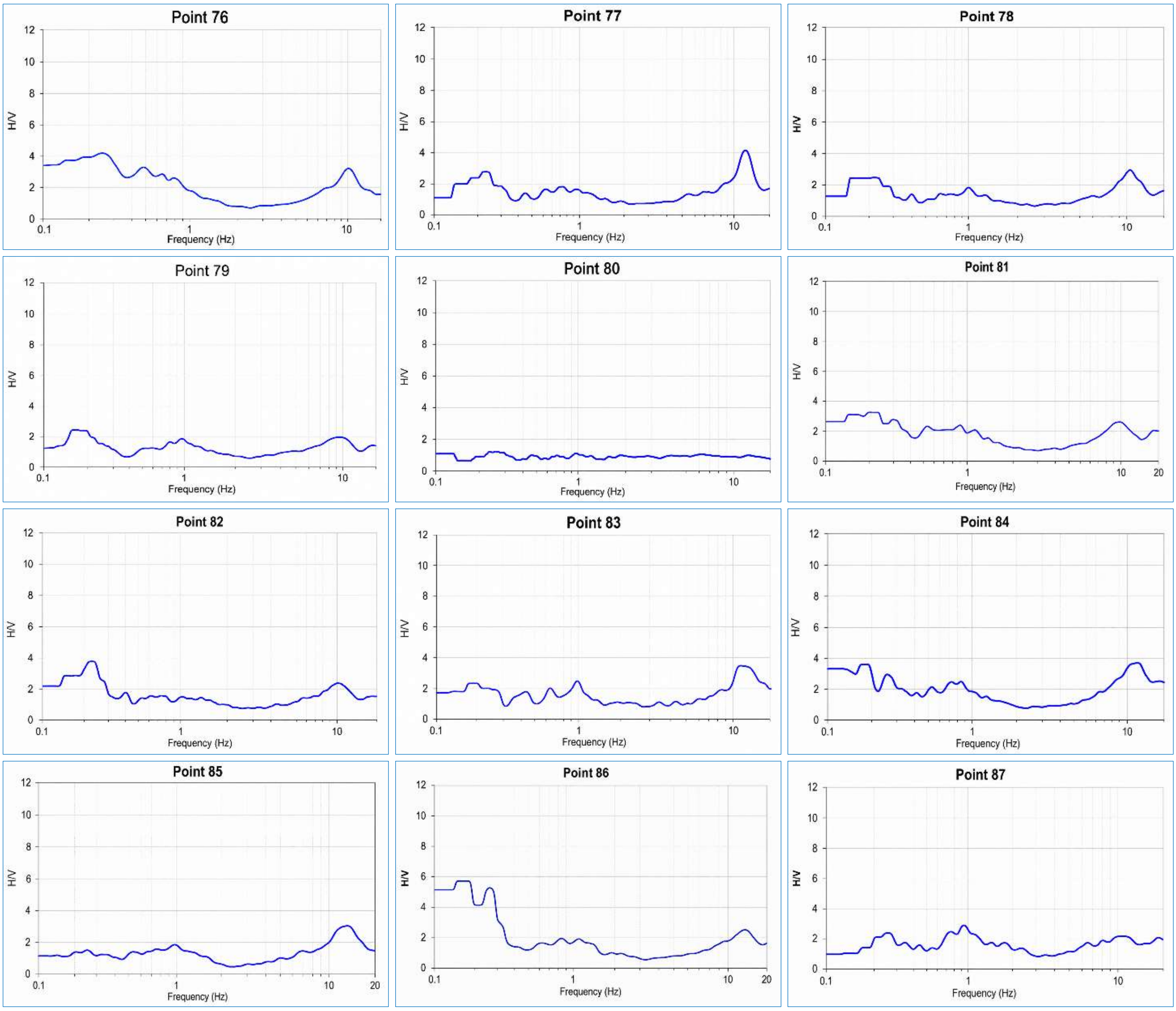

Fig. 10. Microtremor measurement results (H/V-frequency graphs) for points: 76-87

The study was completed with 78 points after eliminating those points where physical conditions were unsuitable for measurement or where sufficient signal-to-noise ratio could not be achieved during measurements (Fig. 6). The f and H/V graphs were prepared by analyzing the microtremor measurement records and are presented in Figs. 7-13. The spatial distribution map of soil dominant frequency was generated using the Kriging interpolation method based on the measured data points (Fig. 14).

The fact that the soil dominant frequency values are less than 1 Hz across most of the study area is the important engineering outcome of this study. In the majority of the H/V curves, the peaks are in the range of 0.12-1.0 Hz, indicating the presence of a thick and relatively loose sedimentary sequence from the surface.

Considering the grain size distribution that tapers from the edges to the center of the Karasu Basin and the location of the study area on a wide alluvial fan, the observed low-frequency character can be said to be consistent with the sedimentary structure of the basin. On the other hand, the study area does not exhibit uniform behavior. The H/V amplitude varies widely between approximately 1.4 and 12; the highest values were observed at point 46 (~12, ~0.51 Hz) and point 61 (~10; 0.65 and 0.86 Hz) (Figs. 7-13).

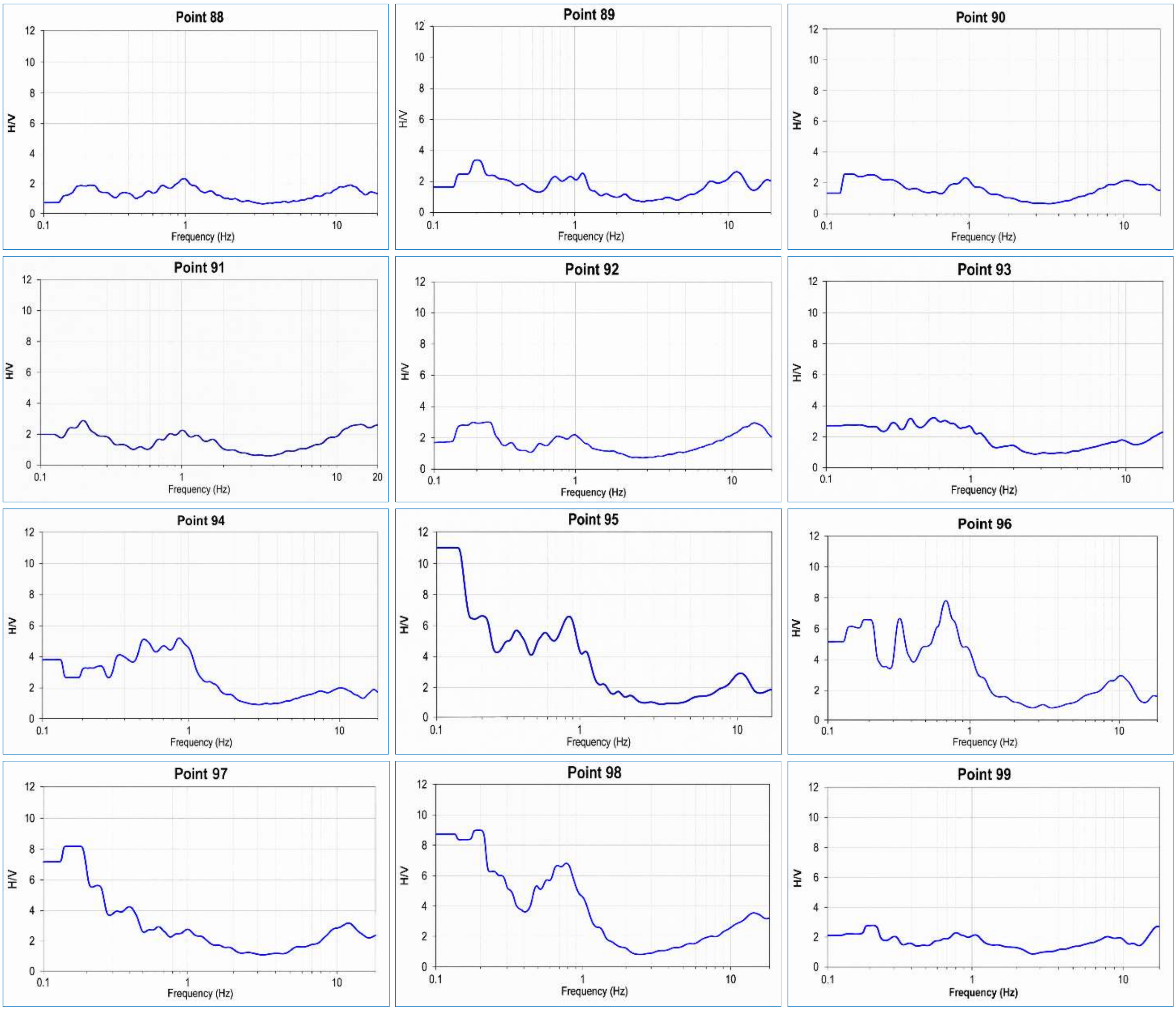

Fig. 11. Microtremor measurement results (H/V-frequency graphs) for points: 88-99

The H/V amplitude values reaching 8 are also observed at points 97, 98, and 108. The observation of many of these high H/V amplitudes at low frequencies is thought to be indicative of a thick, unconsolidated sedimentary environment with a low shear wave velocity.

Also, the H/V curves at points 38, 44, 51, 54, 58, 67, 80, 81, and 88 did not exhibit a distinct peak character. This may be due to the absence of a sharp vertical impedance contrast at these measurement points. The occurrence of high peak values and non-peak H/V responses at relatively close measurement points may reflect local variations in the thickness and stiffness of the near-surface sedimentary layers and associated impedance contrasts.

Such variations may result in differences in the dominant frequency and overall shape of the H/V curves even within a relatively limited area. However, the available single-station measurements do not allow these local variations to be uniquely attributed to a specific subsurface structure.

Further investigations using borehole data and/or complementary geophysical methods would be required to clarify the underlying cause.

One of the strongest pieces of evidence for this heterogeneity is the double-peak curve character observed at measurements 50, 64, 65, 77, 78, 83, 84, 91, and 115. The peaks developing at two different frequencies may indicate two distinct impedance contrasts, one shallow and the other deep. These variations may reflect local differences in sediment stiffness, layer thickness, and impedance contrasts within the alluvial fan deposits.

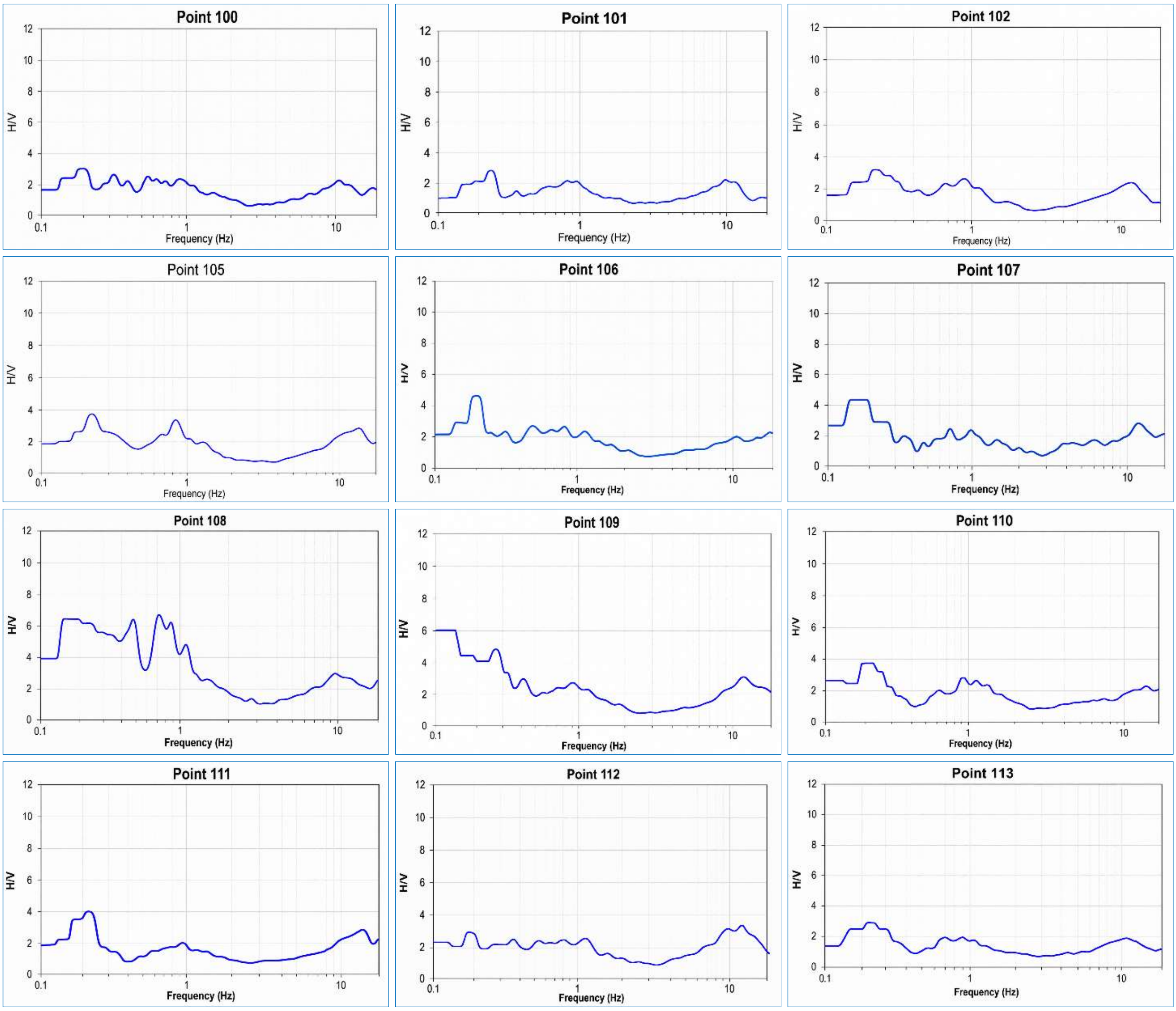

Fig. 12. Microtremor measurement results (H/V-frequency graphs) for points: 100-102 and 105-113

Furthermore, for the measurement points exhibiting double-peak H/V responses, both peaks were considered during the interpretation of the individual H/V curves. However, for the spatial distribution map, the lower of the two soil dominant frequencies was used to provide a conservative representation of the site response (Fig. 14). The fact that sections with uniform grain sizes and lacking fine binding material behave loosely, while well-graded sections behave relatively tightly, is thought to provide the sedimentological justification for the H/V amplitude differences observed within the same sedimentary environment (Fig. 14).

4. Discussion

The findings obtained are in good agreement with current literature data from the Erzurum Karasu Basin and its immediate surroundings. In this study, low soil dominant frequencies (between 0.12 and 15.4 Hz), predominantly below 1 Hz, and H/V amplitude values ranging from 1.4 to 12 were calculated in the alluvial fan west of the Atatürk University Campus, Erzurum, NE Türkiye.

Sarac and Ozer (2024), who examined the central area of the Atatürk University, detected frequencies greater than 2.5 Hz in points representing relatively more stable units; however, they showed that the frequencies decreased in the southeastern sections where the alluvium and sediment thickness increased, and the A value varied between 1 and 6. Karsli and Bayrak (2024) reported soil dominant frequencies between 0.4 and 10 Hz and the A value between 1 and 10 in the Hilalkent region of Erzurum city center, and similarly noted that the period and H/V values increased in the alluvial sections to the west. Sarigul and Bayrak (2025), covering the Yakutiye and Palandoken districts, soil dominant period values were measured between 0.15 and 3.7 seconds, and the H/V ratios were measured between 2.2 and 8.5. Similarly, Aydin et al. (2025), emphasizing the effect of sedimentary layer thickness in the Erzurum Plain, detected higher frequencies such as 0.64-0.81 Hz in areas close to the mountain region, and significantly lower soil dominant frequencies of 0.22-0.27 Hz in Kahramanlar, where sediment thickness increased in the center of the plain. In conclusion, the findings of this study coincide with the results of research showing that thick and loose alluvial deposits in the Karasu Basin can significantly amplify seismic waves.

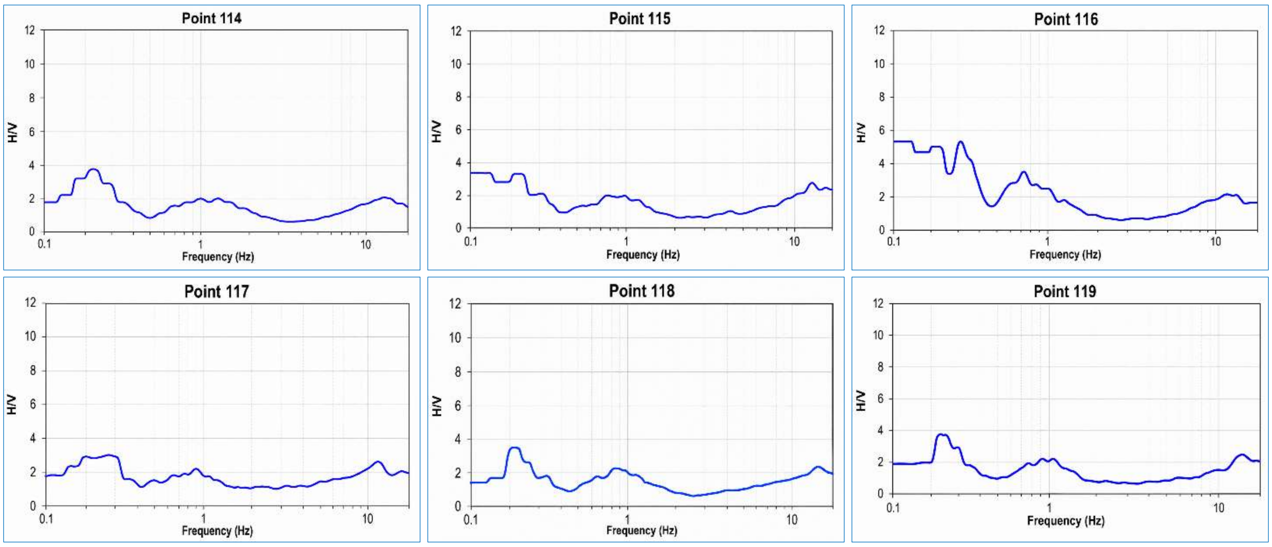

Fig. 13. Microtremor measurement results (H/V-frequency graphs) for points: 114-119

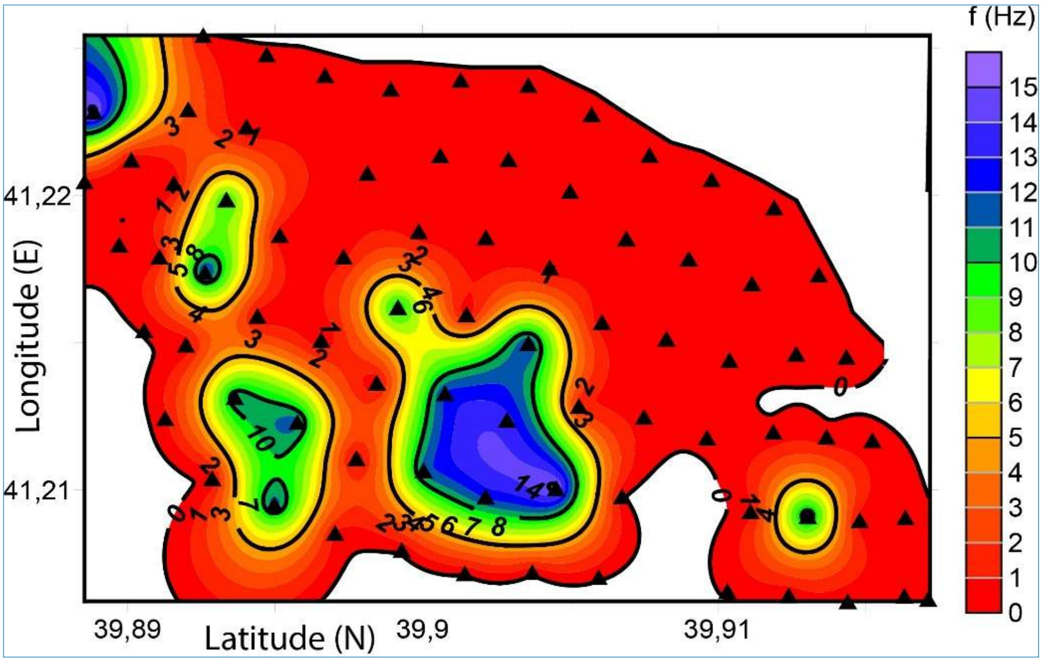

Fig. 14. Map of Soil Predominant Frequency Distribution for the study area

5. Conclusion

Results obtained from microtremor measurements applied at 78 points in the western part of Atatürk University Campus using the Nakamura technique show that the soil dominant frequency values vary between 0.12-15.4 Hz, but are below 1 Hz in many parts of the study area. The fact that the majority of high H/V amplitude values develop at low frequencies indicates a local site effect produced by thick and loose alluvial fan deposits. The occurrence of high peak values and non-peak H/V responses at relatively close measurement points may reflect local variations in the thickness and stiffness of the near-surface sedimentary layers and associated impedance contrasts. However, the available single-station measurements do not allow these local variations to be uniquely attributed to a specific subsurface structure. Further investigations using borehole data and/or complementary geophysical methods would be required to clarify the underlying cause.

Considering the local and regional tectonic setting of Erzurum, incorporating dynamic soil parameters into the design process for future development areas may contribute to reducing potential damage associated with soil-structure interaction and resonance. The soil dominant frequency distribution of the study area is generally less than 1 Hz. The 0.12-1 Hz range corresponds to relatively long site periods and may be relevant for structures whose natural periods fall within this band. Structural resonance, though, cannot be judged from soil dominant frequency alone; it also depends on the structural system and its own dynamic characteristics. These passive-source findings should also be checked and refined with complementary active-source geophysical surveys.

Acknowledgment

This research was carried out within the framework of the MSc thesis of Ulku Nagihan Guzelhan at Atatürk University, Erzurum, Türkiye (Guzelhan, 2023). The geophysical instrumentation employed in this study was supplied by the Earthquake Research Center of Atatürk University, Erzurum.

References

AFAD, 2026. The online earthquake catalog of Ministry of Interior Disaster and Emergency Management Presidency (AFAD) of Türkiye. http://www.deprem.gov.tr.

Akbas, B., Akdeniz, A.N., Altun, A., Balci, I., Bilginer, V.E., 2011. Türkiye Geological Map. General Directorate of Mineral Research and Exploration Ankara-Türkiye. http://www.mta.gov.tr, Ankara-Türkiye, [Accessed January 2026].

Akbayram, K., Bayrak, E., Pamuk, E., Ozer, C., Kiransan, K., Varolgunes, S., 2022. Dynamic sub-surface characteristic and the active faults of the Genc District locating over the Bingol Seismic Gap of the East Anatolian Fault Zone, Eastern Turkey. Natural Hazards 114 (1), 825-847. https://doi.org/10.1007/s11069-022-05414-8.

Akbayram, K., Kiransan, K., Varolgunes, S., Buyukakpinar, P., Karasozen, E., Bayik, C., 2023. Multidisciplinary analyses of the rupture characteristic of the June 14, 2020, Mw 5.9 Kaynarpinar (Karliova, Bingol) earthquake reveal N70E-striking active faults along the Yedisu Seismic Gap of the North Anatolian Fault Zone. International Journal of Earth Sciences 112 (2), 489-509. https://doi.org/10.1007/s00531-022-02256-4.

Akkaya, I., Ozvan, A., 2019. Site characterization in the Van settlement (Eastern Turkey) using surface waves and HVSR microtremor methods. Journal of Applied Geophysics 160, 157-170. https://doi.org/10.1016/j.jappgeo.2018.11.009.

Allen, M., Jackson, J., Walker, R.W., 2004. Late Cenozoic Reorganization of the Arabia-Eurasia Collision and the Comparison of Short-Term and Long-Term Deformation Rates. Tectonics 23, TC2008, https://doi.org/10.1029/2003TC001530.

Anadolu, N.C., Kalyoncuoglu, U.Y., 2010. Seismicity and Seismic Hazard Analysis for the Southeastern Anatolia Region. Suleyman Demirel University, Journal of the Institute of Science 14 (1), 84-94. (in Turkish).

Arpat, E.,1965. Ilica-Askale (Erzurum) Arasindaki Sahanin ve Kuzeyinin Genel Jeolojisi- Petrol Imkanlar 1, MTA Raporu. No: 4040, Ankara, Türkiye.

Ates, E., 2021. Mikrotremor, Deprem ve Yuzey Dalgalarinin Cok Kanalli Analiz Yontemi Kayitlari Kullanilarak Zemin Ozelliklerinin Belirlenmesi: AFAD Kampusunden Ornek Bir Uygulama. Artvin Coruh Universitesi, Dogal Afetler Uygulama ve Arastirma Merkezi, Dogal Afetler ve Cevre Dergisi 7 (2), 240-251.

Aydin, O.L., Karimi, B., Kazaz, I., 2025. Geotechnical and geophysical investigations on local site effects in Erzurum, Türkiye. Natural Hazards 121, 12837-12861. https://doi.org/10.1007/s11069-025-07298-w.

Barka, A., Bayraktutan, M.S., 1985. Active fault patterns in the vicinity of the Karasu Basin. Abstract, TJK Geological Congress 1985, p. 11.

Bayrak, E., Ozer, C., Perk, C., 2020. Erzurum ve Cevresi Icin Gerilme Tensor ve Coulomb Analizleri (in Turkish with English abstract). Turk Deprem Arastirma Dergisi 2 (1), 101-114. https://doi.org/10.46464/tdad.737222.

Bayrak, E., 2022. Investigation of soil dynamic properties using horizontal-to-vertical spectral ratio for Eastern Pontides, Northeast Turkey. Environmental Earth Sciences 81 (21), 514.

Bayraktutan, M.S., Merefield, J.R., Grainger, P., Evans, B.M., Yilmaz, M., Kalkan, E., 1996. Regional gas geochemistry in an active tectonic zone, Erzurum Basin, eastern Turkey. Quarterly Journal of Engineering Geology 29, 209-218. https://doi.org/10.1144/GSL.QJEGH.1996.029.P3.04.

Bayraktutan, M.S., Villa, I., 1986. Geochronology and geochemistry of Paleogene Volcanic Basement of the Narman Basin, NE Turkey. International Conference on Geochronology, Cambridge, Terra Cognita, 6 (2), 186.

Beker Usta, Y., Sayil, N., 2024. Microzonation based on site effect using active and passive source surface waves data: The case of Gumushane. Gumushane University Journal of Science 14 (2), 639-653. https://doi.org/10.17714/gumusfenbil.1418648.

Beker, Y. 2011. KTU Yerleskesinde Mikrotremor Yontemiyle Zemin Ozelliklerinin Belirlenmesi. Y. Lisans Tezi, Karadeniz Teknik Universitesi Fen Bilimleri Enstitusu, Trabzon.

Bilgin, Y., 2023. Kamu binalarinda deprem-zemin-yapi etkilesiminin arastirilmasi; Erzurum ornegi. Yuksek Lisans Tezi, Atatürk Universitesi, Fen Bilimleri Enstitusu, Erzurum, Türkiye.

Bonilla, L.F., Steidl, J.H., Lindley, G.T., Tumarkin, A.G., Archuleta, R.J., 1997. Site amplification in the San Fernando Valley, California: Variability of site-effect estimation using the S-wave, coda, and H/V methods. Bulletin of the Seismological Society of America 87 (3), 710-730. https://doi.org/10.1785/BSSA0870030710.

Bozkurt, E., 2001. Neotectonics of Turkey - a synthesis. Geodinamica Acta 14 (1-3), 3-30. https://doi.org/10.1080/09853111.2001.11432432.

Caielli, G., de Franco, R., Di Fiore, V., Albarello, D., Catalano, S., Pergalani, F., .Cavuoto, G., Cercato, M., Compagnoni, M., Facciorusso, J., Famiani, D., Ferri, F., Imposa, S., Martini, G., Paciello, A., Paolucci, E., Passeri, F., Piscitelli, S., Puzzilli, L.M., Vassallo, M., 2020. Extensive surface geophysical prospecting for seismic microzonation. Bulletin of Earthquake Engineering 18, 5475-5502. https://doi.org/10.1007/s10518-020-00866-4.

Celik, S., Ozyazicioglu, M., Sahin, R., Uysal, H., Cakici, F.Z., Kalkan, E., 2021. The destruction of Erzurum ski-jumping complex by a landslide: evaluation of an engineering design failure. Natural Hazards 107 (1), 475-496.

Dogru, A., Gorgun, E., Aktug, B., Ozener, H., 2018. Seismic hazard assessment of the central North Anatolian Fault (Turkey) from GPS-derived strain rates and b-values. Geomatics, Natural Hazards and Risk 9 (1), 356-367. https://doi.org/10.1080/19475705.2018.1441193.

Duman, T.Y., Emre, O. 2013. The East Anatolian Fault: geometry, segmentation and jog characteristics. Geological Society Special Publications-London 372, 495-529. https://doi.org/10.1144/SP372.1.

Emre, O., Duman, T.Y., Ozalp, S., Elmaci, H., Olgun, S., Saroglu, F. 2013. 1/1.250.000 scaled Türkiye active fault map. General Directorate of Mineral Research and Exploration Special Publication, http://www.mta.gov.tr.

Emre, O., Duman, T.Y., Ozalp, S., Saroglu, F., Olgun, S., Elmaci, H., Can, T. 2018. Active fault database of Turkey. Bulletin of Earthquake Engineering 16, 3229-3275. https://doi.org/10.1007/s10518-016-0041-2.

Ercan, T., Fujitani, T., Matsuda, J., Notsu, K., Tokel, S., Ui, T., 1990. Dogu ve Guneydogu Anadolu Neojen Volkanitlerine Iliskin Yeni Jeokimyasal, Radyometrik ve Izotopik Verilerin Yorumu. MTA Dergisi 110, 143-164.

Erdik, M., Demircioglu, M., Sesetyan, K., Durukal, E., Siyahi, B., 2004. Earthquake hazard in Marmara Region, Turkey. Soil Dynamics and Earthquake Engineering 24 (8), 605-631. https://doi.org/10.1016/j.soildyn.2004.04.003.

Fadli, D. I., Awaliyah, I. A., Hadi, A. I., Farid, M., Akbar, A. J., Refrizon, R., 2023. Microzonation Site Effects and Shear Strain during Earthquake Induced Landslide Using HVSR Measurement in Ulu Mana Sub-District, South Bengkulu Regency Indonesia. Jurnal Penelitian Pendidikan IPA 9 (2), 592-599.

Goncuoglu, M.C., Kozlu, H., Dirik, K., 1997. PreAlpine and Alpine terranes in Turkey: explanatory notes to the terrane map of Turkey. Annales Geologiques des Pays Helleniques 37, 515-536.

Gulen, L., Pinar, A., Kalafat, D., Ozel, N., Horasan, G., Yilmazer, M., Isikara, A.M., 2002. Surface fault breaks, aftershock distribution, and rupture process of the August 17, 1999 Izmit, Turkey Earthquake. Bulletin of the Seismological Society of America 92 (1), 230-244. https://doi.org/10.1785/0120000815.

Guzelhan, U.N. 2023. Atatürk Universitesi kampusu batisinin zemin dinamik parametrelerinin belirlenmesi, Yuksek lisans tezi. Atatürk Universitesi, Fen Bilimleri Enstitusu, Erzurum, Türkiye, (in Turkish).

Huang, Q., Oncel, A.O., Sobolev, G.A., 2002. Precursory seismicity changes associated with the 1999 August 17 Izmit (Turkey) earthquake. Geophysical Journal International 151 (1), 235-242. https://doi.org/10.1046/j.1365-246x.2002.01762.x.

Hubert-Ferrari, A., Armijo, R., King, G., Meyer, B., Barka, A. 2002. Morphology, displacement, and slip rates along the North Anatolian Fault. Journal of Geophysical Research: Solid Earth 107 B10, 1-33. https://doi.org/10.1029/2001JB000393.

Ibs-von Seht, M., Wohlenberg, J., 1999. Microtremor measurements used to map thickness of soft sediments. Bulletin of the Seismological Society of America 89 (1), 250-259. https://doi.org/10.1785/BSSA0890010250.

Kalkan, E., Yarbasi, N., 2007. Karasu Havzasi ve Havza Guneyindeki Aluvyon Cokellerin Sivilasma Potansiyeli. 60. Türkiye Jeoloji Kurultayi, Türkiye, 16-22 Nisan 2007, Ankara, 336-338.

Karaca, S., Bayram, H., 2019. Erzurum Havzasi'nda Yerlesme ve Zemin Iliskisi. Al-Farabi International Journal on Social Sciences 3 (2), 80-98.

Karsli, F., Bayrak, E. 2024. Single station microtremor surveys for site characterization: A case study in Erzurum city, eastern Turkey. Earthquake Engineering and Engineering Vibration, 23 (3), 563-576. https://doi.org/10.1007/s11803-024-2257-5.

Keskin, M., 1998. Erzurum- Kars Platosunun Carpisma Kokenli Volkanizmasinin Volkano Stratigrafisi ve Yeni K-Ar Yas Gruplari Isiginda Evrimi: Kuzeydogu Anadolu. MTA Dergisi 120, 135-157.

Keskinsezer, A., Dag, E., 2019. Investigating of soil features and landslide risk in Western-Atakent (Istanbul) using resistivity, MASW, Microtremor and boreholes methods. Open Geosciences 11 (1), 1112-1128. https://doi.org/10.1515/geo-2019-0086.

Kocyigit, A., Canoglu, M.C., 2017. Neotectonics and seismicity of Erzurum pull-apart basin, East Turkey. Russian Geology and Geophysics 58 (1), 99-122. https://doi.org/10.1016/j.rgg.2016.04.015.

Kocyigit, A., Ozturk, A., Inan, S., Gursoy, H., 1985. Karasu Havzasi'nin (Erzurum) Tektonomorfolojisi ve Mekanik Yorumu. Cumhuriyet Universitesi Muhendislik Fakultesi Yer Bilimleri Dergisi 2 (1), 3-15.

Lermo, J., Chavez-Garcia, F.J., 1993. Site effect evaluation using spectral ratios with only one station. Bulletin of the Seismological Society of America 83 (5), 1574-1594. https://doi.org/10.1785/BSSA0830051574.

Lermo, J., Chavez-Garcia, F.J., 1994. Are microtremors useful in site response evaluation? Bulletin of the Seismological Society of America 84 (5), 1350-1364. https://doi.org/10.1785/BSSA0840051350.

McKenzie, D., 1978. Active tectonics of the Alpine-Himalayan belt: the Aegean Sea and surrounding regions. Geophysical Journal International 55 (1), 217-254. https://doi.org/10.1111/j.1365-246x.1978.tb04759.x.

Nakamura, Y. 2019. What is the Nakamura method? Seismological Research Letters 90 (4), 1437-1443. https://doi.org/10.1785/0220180376.

Nakamura, Y., 1989. A method for dynamic characteristics estimation of subsurface using microtremor on the ground surface. Quarterly Report of Railway Technical Research Institute 30 (1), 25-33.

Oncu, L., Kalkan, E., 2023. Liquefaction Analysis for Aziziye District (Erzurum, NE Turkey) Soils According to Turkey Building Earthquake Regulations 2018 (TBER-2018). International Journal of Innovative Research and Reviews 7 (2), 70-76.

Oncu, L., Kalkan, E., Yilmaz, M.K., 2025. Erzurum Aziziye Ilcesi Zeminlerinin Deprem Etkisi Altindaki Sivilasma Davranisinin Incelenmesi. 10. Geoteknik Sempozyumu 7-8 Kasim 2025, Kocaeli, Türkiye.

Ozcan, G., 2013. Yapilarin dinamik ozelliklerinin mikrotremor olcumleri ile belirlenmesi. Master's thesis, Pamukkale Universitesi, Fen Bilimleri Enstitusu, Denizli, Türkiye.

Ozer, C., 2019. Erzurum ve Cevresi Yerel Zemin Etkilerinin SSR ve HVSR Yontemleri Kullanilarak Arastirilmasi. Dokuz Eylul Universitesi Muhendislik Fakultesi Fen ve Muhendislik dergisi 21 (61), 247-257. https://doi.org/10.21205/deufmd.2019216124.

Peynirci, O., Demirtas, R., Yagyemez, B., Ugras, M., 2010. Erzurum Ili Buyuksehir Belediyesi Yerlesim Alaninin 1/5000 olcekli Nazim Imar Planina Esas Jeolojik-Jeoteknik Etut Raporu, Erzurum.

Putti, S.P., Satyam, N., 2020. Evaluation of site effects using HVSR microtremor measurements in Vishakhapatnam (India). Earth Systems and Environment 4, 439-454. https://doi.org/10.1007/s41748-020-00158-6.

Reilinger, R.E., Mcclusky, S.C., Oral, M.B., King, R.W., Toksoz, M.N., 1997. Global Positioning System Measurements of Present-Day Crustal Movements in the Arabia-Africa-Eurasian Plate Collision Zone. Journal of Geophysical Research 102, 9983-9999. https://doi.org/10.1029/96JB03736.

Sarac, B., Ozer, C., 2024. Soil dynamic features of Atatürk University Campus (Erzurum), eastern Türkiye, by microtremor method. Baltica 37 (2), 125-136. https://doi.org/10.5200/baltica.2024.2.4.

Sarigul, S., Bayrak, E. 2025. Investigation of local soil properties of Erzurum province (Eastern Türkiye) by Horizontal/Vertical Spectral ratio method. Bulletin of the Mineral Research and Exploration 176 (176), 1-2. https://doi.org/10.19111/bulletinofmre.1574914.

Saroglu, F., Yilmaz, Y., 1986. Geological Evolution and Basin Models During Neotectonic Episode in the Eastern Anatolia. Bulletin of the Mineral Research and Exploration 107, 70-93. https://izlik.org/JA63RA59BK.

Sengor, A.M.C., 1979. The North Anatolian Fault; Its Age, Offset and Tectonic Significance. Journal of Geology 136, 269-282. https://doi.org/10.1144/gsjgs.136.3.0269.

Sengor, A.M.C., Yilmaz, Y., 1981. Tethyan evolution of Turkey: A plate tectonic approach. Tectonophysics 75 (3-4), 181-241. https://doi.org/10.1016/0040-1951(81)90275-4.

Tavlasoglu, E., 2021. Erzurum Aziziye Bolgesi Jeolojik ve Jeoteknik Calismasi. Yuksek lisans Tezi, Atatürk Universitesi, Fen Bilimleri Enstitusu, Erzurum, Türkiye.

Timur, E., 2000. Stratigraphy of the Yesircol Mountain (Askale-Erzurum) and Surrounding Area. Istanbul University, Faculty of Engineering, Journal of Earth Sciences 13 (1-2), 85-99.

Trifonov, V.G., Sokolov, S.Y., 2014. Late Cenozoic Tectonic Uplift Producing Mountain Building in Comparison with Mantle Structure in the Alpine-Himalayan Belt. International Journal of Geosciences 5 (5), 497-518. https://doi.org/10.4236/ijg.2014.55047.

Wathelet, M., Chatelain, J.L., Cornou, C., Di Giulio, G., Guillier, B., Ohrnberger, M., Savvaidis, A., 2020. Geopsy: a user-friendly open-source tool set for ambient vibration processing. Seismological Research Letters 91 (3), 1878-1889. https://doi.org/10.1785/0220190360.

Yalcin, H., Gulen, L., Utkucu, M., 2013. Türkiye ve Yakin Cevresinin Aktif Faylari Veri Bankasi ve Deprem Tehlikesinin Arastirilmasi. Yerbilimleri. Hacettepe Universitesi Yerbilimleri Uygulama ve Arastirma Merkezi Bulteni 34 (3), 133-160. https://izlik.org/JA42YD88MA.

Yalcinkaya, E., 2010. Zemin neden bu kadar onemli. Jeofizik Bulteni 63, 77-80.

Yarbasi, N., Kalkan, E. 2009. Geotechnical Mapping for Alluvial Fan Deposits Controlled by Active Faults: A Case Study in the Erzurum, NE Turkey, Environmental Geology 58, 701-714. https://doi.org/10.1007/s00254-008-1544-1.