Investigation of the Effects of Waste Tire, Water Content, and Relative Density on Soil Dominant Frequency in Separate Grained Soils by Microtremor Method

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ABSTRACT

This paper presents the effects of waste tires, water content, and relative density on the soil dominant frequency based on experiment. Cylindrical molds with a diameter of 30 cm and height of 50 cm are prepared to understand the effects of these materials. The molds are filled with sand at different relative densities (60% and 80%). In addition, samples are prepared by adding waste tire particles at different rates (0%, 0.5%, 1%, and 2%) to the sand to achieve different relative densities and water contents (0%, 5%, 10%, and 15%). The soil dominant frequency and horizontal/vertical (H/V) amplitude are determined using the microtremor technique by measuring each cylinder for 60 min using a broadband seismometer. Microtremor data are analyzed using the H/V spectral ratio (Nakamura) method. The experimental result shows that the waste tire particles added to the sand decrease the H/V amplitude. The most suitable environment features a relative density of 60%, which is achieved using 1% waste tires and 0% water content. Meanwhile, the most suitable environment has been achieved using 0% water content and 0.5% waste tire ratio for 80% relative density. Using the prepared composite material with waste tires as an additive on the soil may reduce the destructive effects of earthquakes.

Keywords: Microtremor; Soil Sominant Frequency; Water Content; Relative Density; Waste Tire.

INTRODUCTION

Currently, significant amounts of waste are being generated due to an increase in population. These waste materials limit the use of utility areas and cause environmental pollution. All types of rubber waste are used in machinery and materials. A tire releases 1,479 kg of solid rubber waste into the environment during its lifetime (Altin et al., 2013). Waste tires-soil mixtures can be used as alternative backfill material (Zornberg et al., 2004). These waste materials are used in many applications such as roads, retaining walls, and backfill materials. Waste rubber particle–floor mixtures have been used as lightweight filling materials in many filling and bearing structures (Bosscher et al., 1997; Humphrey and Katz, 2000; Dickson et al., 2001). Waste rubber particles of different sizes were obtained mechanically and used as soil additives. Waste materials contribute significantly to the economy and reduce environmental pollution, as well as serve as important seismic isolation materials for engineering applications (Cakici et al., 2019).

The determination of earthquake–soil–structure relationships is particularly important for reducing potential damage by earthquakes. Building damage caused by earthquakes changes depending on the geological features, soil dynamic characteristics, and building status. Changes occur in the amplitude of seismic waves depending on the physical properties of the soil environment in which they propagate (Bonnefoy-Claudet et al. 2008). In this regard, seismic microzonation must be investigated to prevent earthquake damage (Fabozzi et al., 2020). Understanding the dynamic properties of soils is key for solving geotechnical problems (Guler and Afacan, 2019). The deformation level of soil due to earthquake waves significantly affects soil–structure interactions (Subasi et al., 2019). Microtremors can provide information for solving problems of natural origins and are widely used to estimate dynamic soil parameters (Lermo and Chávez-García, 2014a, b). Microtremors are low-energy seismic waves with amplitudes at the micron level and are assumed to comprise mainly surface waves with periods of 0.05 to 2 s (Kanai and Tanaka 1954, 1961; Nakamura 1989). The most important feature of microtremors is their significant point-to-point change. These changes are related to the shallow geological features of the measured location (Parolai, 2012) and are widely used in geotechnical engineering to understand local soil dynamic conditions. Kanai and Tanaka (1961) reported that a close relationship exists between microtremors and earthquakes, based on the method they developed. The dominant frequencies of soil during earthquakes exhibit a close relationship with the soil dominant frequency of the location obtained from microtremor measurements (Kanai and Tanaka, 1961). Furthermore, they stated that this similarity was high, particularly when the location was plain and uniform. The microtremor method is widely used for determining soil dynamic parameters owing to its easy application and rapid analysis (Tun et al. 2016; Pamuk et al., 2017, 2018). Nakamura stated that soil effects can be calculated by proportioning the horizontal spectra of soil to the vertical spectra in microtremor measurements on a point basis (Nakamura, 1989). The Nakamura method not only determines the soil dominant frequency, but also calculates the soil amplification factor using the horizontal/vertical (H/V) amplitude of microtremors (Nakamura, 2019).

In this study, we investigate the effect of waste tire particles on the H/V amplitude and soil dominant frequency in poorly graded sandy soil with different water contents at relative densities of 60% and 80%. Along with the sandy soil, waste rubber pieces in different proportions were added to cylindrical containers. These samples have different water contents and relative densities. Horizontal to vertical spectral ratio (HVSR) analyses were performed on the prepared samples using microtremor data from the experiment.

MATERIAL AND METHOD

In this study, sandy soil, waste tires, and cylindrical sample containers were used. Sandy soil was obtained from the shore of the Aras River in the Horasan–Erzurum district (Turkey). Sieve analysis, grain unit weight, maximum and minimum void ratios for sandy soil were determined in the laboratory based on the Turkish Standard 1900 (TSE, 2016). Information regarding the grain unit weight and the maximum and minimum space rates of the waste rubber material was obtained from the manufacturer.

The effects on the soil dominant frequency and H/V amplitude of the samples in 32 cylindrical containers were calculated, and the basic physical properties of the soil were determined. A 0.5 mm-thick sheet was used to construct the cylindrical containers, in which sand and waste tires were placed. The containers featured a diameter of 30 cm and a height of 50 cm (see Figures 1a and 1b).

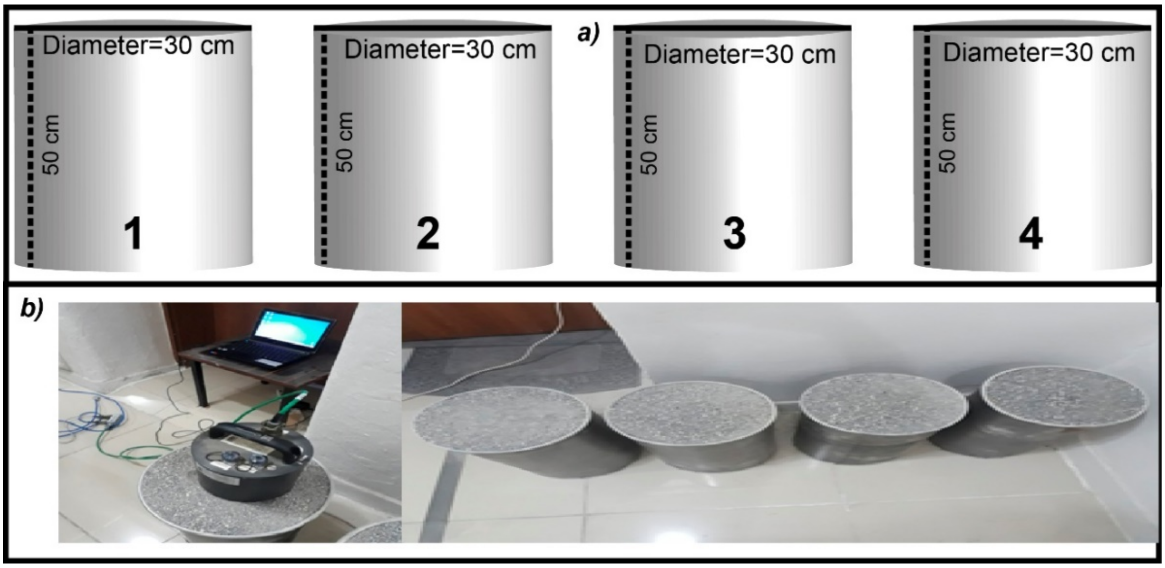


Figure 1 a. Cylinders created for current study. **b.** Experimental setup.

The study comprised three stages. In the first stage, the physical properties (γ_s, e, e_{max}, and e_{min}) and grain size distribution of the sandy soil were determined based on laboratory studies. The sandy soil was classified as poorly graded sand (SP) based on the Unified Soil Classification System classification method. The grain size distribution curve of the sandy soil is presented in Figure 2. Some of the physical properties of the sandy soil and those obtained from the manufacturer of waste tires are listed in Tables 1 and 2, respectively.

Table.1. Physical properties of sandy soil.

Soil material	**γ_s (kN/m^3)**	**e (% 60 Dr)**	**e (% 80 Dr)**	**e max**	**e min**
Sand	23,42	0,72	0,636	0,98	0,55

Table.2. Physical properties of waste material

Waste	**γ_s (kN/m^3)**	**e (% 60 Dr)**	**e (% 80 Dr)**	**e max**	**e min**
Waste tire	9,89	0,95	0,81	1,37	0,67

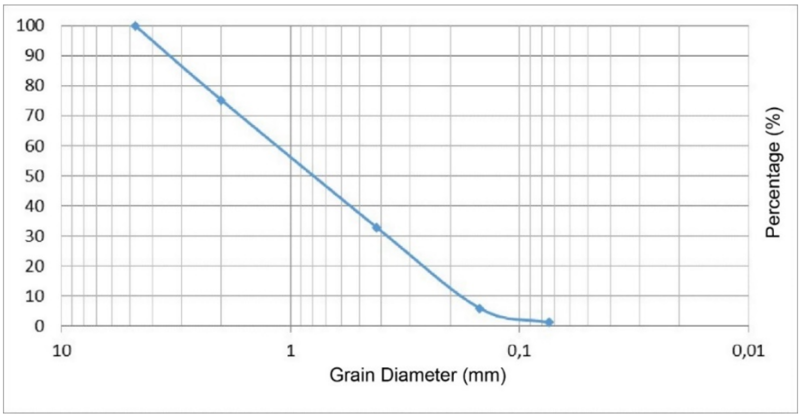


Figure 2. Grain size distribution curve of sandy soil.

In the second stage, waste tire particles equivalent to the mass of the volume corresponding to the amount of sand to be removed from the total sand were added. Different amounts of waste tire particles (0%, 0.5%, 1%, and 2%) were added to the sandy soil such that their relative densities (D_r = 60%) remained unchanged. They were mixed until a homogeneous mixture was achieved. Subsequently, the prepared mixture was placed in a suitable cylindrical die. The samples were prepared by adding different amounts of water (0%, 5%, 10%, and 15%) at relative densities of 60% and 80% (Table 3).

Table.3. Parameters for different tests performed experimentally in current study.

%60 Relative Density				**%80 Relative Density**			
No	**Water content (%)**	**Sand (%)**	**Waste Tire (%)**	**No**	**Water content (%)**	**Sand (%)**	**Waste Tire (%)**
1	0	100	0	**17**	0	100	0
2	0	99,5	0,5	**18**	0	99,5	0,5
3	0	99	1	**19**	0	99	1
4	0	98	2	**20**	0	98	2
5	5	100	0	**21**	5	100	0
6	5	99,5	0,5	**22**	5	99,5	0,5
7	5	99	1	**23**	5	99	1
8	5	98	2	**24**	5	98	2
9	10	100	0	**25**	10	100	0
10	10	99,5	0,5	**26**	10	99,5	0,5
11	10	99	1	**27**	10	99	1
12	10	98	2	**28**	10	98	2
13	15	100	0	**29**	15	100	0
14	15	99,5	0,5	**30**	15	99,5	0,5
15	15	99	1	**31**	15	99	1
16	15	98	2	**32**	15	98	2

In the third stage, microtremor measurements were conducted for at least 60 min using a CMG-6TD seismometer at a sampling interval of 100 Hz. A seismometer was placed on the prepared cylindrical molds, and the effects of each sample on the soil dominant frequency and H/V amplitude values were analyzed. The Geopsy software (Wathelet et al. 2020) was used to determine the H/V amplitude and soil dominant frequency.

The Nakamura method assumes that the change in the amplitude of the vertical component waves is not extreme and that the horizontal component waves can be affected by the features of the soil through which they pass (Nakamura 1989; 2019). The vertical component cannot be amplified in the frequency range in which the horizontal component receives a large H/V amplitude (Nakamura, 2000; Yalcinkaya, 2010; Pamuk et al., 2017, 2018). The local soil effect can be calculated using Eq. 1, based on the HVSR method (Nakamura, 1989).

$$HVSR = \sqrt{NS^2 + EW^2}/V \tag{1}$$

The local site effect from the surface geology can be predicted using the spectral ratio of the horizontal and vertical components. In the evaluation, after the trend effect of the microtremor data was removed, a band-pass filter ranging between 0.5 and 20 Hz with 25 s windows was used, and a 5% cosine filter was applied.

RESULTS

The H/V amplitudes and soil dominant frequencies were obtained based on the microtremor measurement results of 32 samples with different tire waste ratios and water contents (see Table 4). The H/V amplitude–water content, H/V amplitude–waste rate, soil dominant frequency–water content, and soil dominant frequency–waste ratio relationships were investigated using the data in Table 4 for relative densities of 60% and 80% (Figures 3 and 4, respectively).

Table 4. H/V amplitude and soil dominant frequency values of the experiments.

Experiment Number	Soil Dominant Frequency (Hz)	H/V Amplitude	Experiment Number	Soil Dominant Frequency (Hz)	H/V Amplitude
1	10.28	6.29	**17**	8.53	14.90
2	22.67	6.93	**18**	16.37	14.89
3	24.88	5.22	**19**	8.14	8.35
4	24.88	5.23	**20**	14.91	6.31
5	10.77	7.84	**21**	12.38	7.05
6	22.67	9.22	**22**	17.15	14.46
7	24.88	7.04	**23**	8.14	10.55
8	17.96	5.64	**24**	16.37	9.21
9	10.77	7.32	**25**	8.14	9.63
10	21.64	8.80	**26**	17.96	14.72
11	24.88	7.86	**27**	7.77	10.48
12	17.96	5.76	**28**	16.37	8.60
13	9.36	10.17	**29**	8.14	9.55
14	16.37	5.91	**30**	18.82	14.81
15	29.97	9.19	**31**	7.77	10.50
16	17.96	6.00	**32**	15.62	8.28

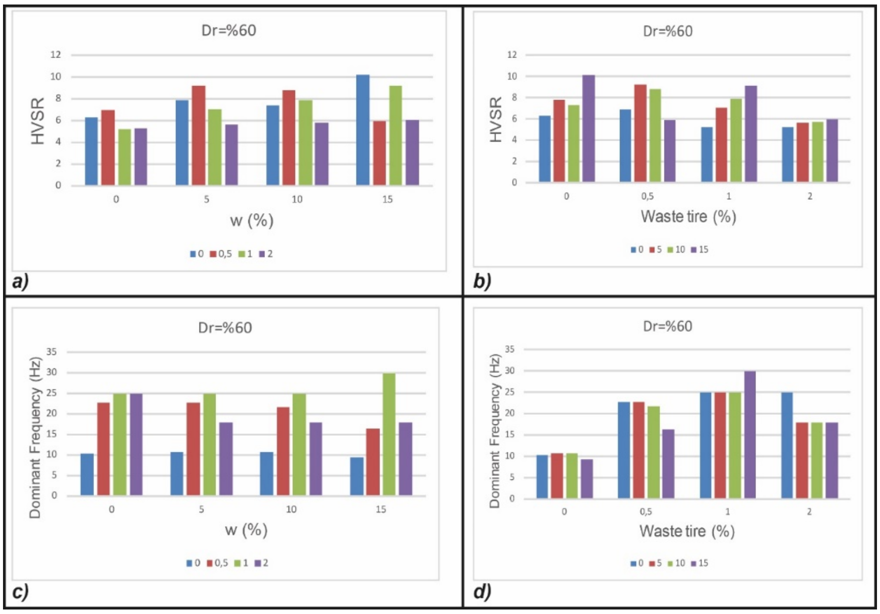


Figure 3 a H/V amplitude–water content relationship, b H/V amplitude–waste tire relationship, c soil dominant frequency–water content relationship, and d soil dominant frequency–waste tire relationship for 60% relative density (Dr).

The dominant frequency of the soil increased with the waste tire ratio. The H/V amplitude increased until a waste tire ratio of 0.5 % and decreased thereafter for a the case of 60% relative density with 0% water content (Figure 3 and Table 4). In cases where the water content was 5% and 10%, except when the waste tire ratio was 0.5%, the soil dominant frequency increased up to a waste tire ratio of 1% and then decreased thereafter; however, the H/V amplitude of the soil decreased. In the case where the water content is 15%, the water content of the soil dominant frequency tends to be similar to 5% and 10% while the H/V amplitude tends to decrease overall with the increase in waste tire ratio. There was an increase of 0.5% and 2% of the waste tire while H/V amplitude was reduced with the increase of the waste tire rate for 80% relative density with the water contents of 0%, 5%, 10%, and 15% (except 0%). Meanwhile, the soil dominant frequency values of the samples with 0% and 1% waste tire contents at all water content rates were similar (Figure 4 and Table 4).

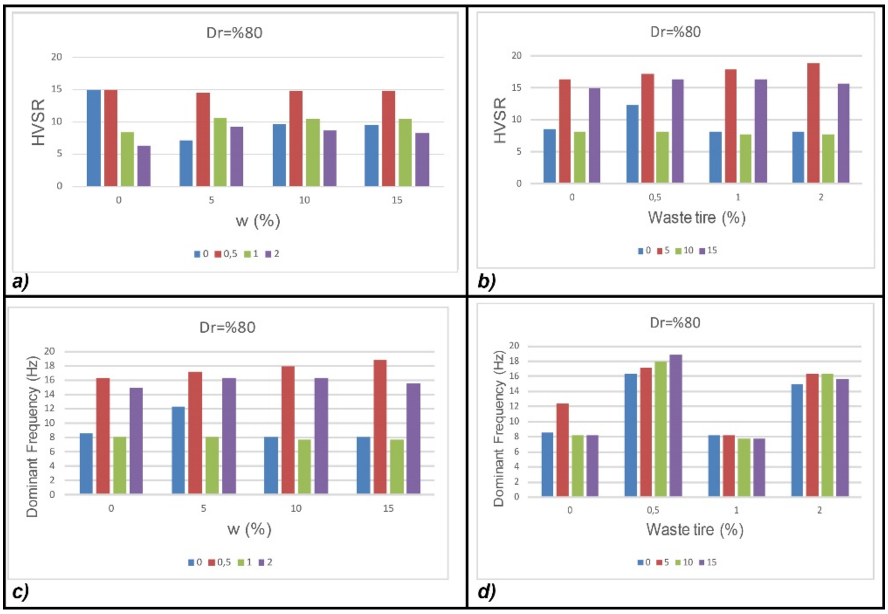


Figure 4 a H/V amplitude–water content relationship, b H/V amplitude–waste tire relationship, c soil dominant frequency–water content relationship, and d soil dominant frequency–waste tire relationship for 80% relative density (Dr).

For the case of 60% relative density, the soil dominant frequency decreased and the H/V amplitude increased as the water content increased at a waste rate ratio of 0%. Meanwhile, the soil dominant frequency decreased and the H/V amplitude increased (except for w = 15%) as the water content increased at a waste rate of 0.5%. Both the soil dominant frequency and H/V amplitude increased with the water content at a 1% waste rate. The rate of waste was 2%; meanwhile, the soil dominant frequency decreased and the H/V amplitude values increased as the water content increased.

At 80% relative density, the soil dominant frequency and H/V amplitude decreased as the water content increased in the 0% waste tires. Meanwhile, the dominant soil frequency increased with the water content increased, and the H/V amplitude values were similar in the 0.5% waste tire. The soil dominant frequency decreased as the water content increased, whereas the H/V amplitude increased in the 1% waste tires. When the waste rate was 2%, the soil dominant frequency and H/V amplitude increased (excluding the case with 15% water content) as the water content increased.

For the case of 60% relative density, when the soil dominant frequency increased, the H/V amplitude decreased from 0.0% to 2.0% for the waste tires with 98.0% sand and 0% water content. Whereas the soil dominant frequency increased with the waste tire ratio up to 2%, it decreased in the 2% waste tires for the combination of 0% waste tire, 100% sand, and 5% water content. Except for the case of 0.5% waste tire ratio, the overall H/V amplitude decreased in general. Increasing the waste tire ratio in the combination comprising 0.5% waste tires, 99.5% sand, and 10% water increased the soil dominant frequency in general. Although the soil dominant frequency decreased partially for the 2% waste tire ratio, the value exceeded the soil dominant frequency of the soil without waste tires. Increasing the proportion of waste tires in the combination comprising 0.5% waste tire, 99.5% sand, and 15% water content generally increased the soil dominant frequency, whereas the H/V amplitude decreased in general (Figure 3 and Table 4).

For the case of 80% relative density, the soil dominant frequency reached the maximum value in the 0.5% waste tires, and the H/V amplitude increased when the sand and water contents were 99.5% and 5%, respectively. The dominant frequency increased in the combination comprising 0.5% waste tire, 99.5% sand, and 10% water. However, it increased in the 1% waste tires and decreased in the 2% waste tires (Figure 4 and Table 4).

Although the soil dominant frequency increased in the 1% waste tires for all water contents with a relative density of 60%, the proportion of 1% waste tires with a relative density of 80% exhibited a partial decrease. The H/V amplitude reached a maximum value in the 0.5% waste tires with 0% water content at 60% relative density. Meanwhile, the H/V amplitude decreased with as the amount of waste tires with 80% relative density and 0% water content increased. The H/V amplitude reached its maximum value in the 0.5% waste tire with 5% water content at 60% relative density. Similarly, the H/V amplitude reached its maximum value in the 0.5% waste tires with 5% water content at 80% relative density. The H/V amplitude increased in the case with 10% water content at 60% relative density. The H/V amplitude reached a maximum value for the case with 10% water content and 0.5% waste tire at 80% relative density. The maximum H/V amplitude was obtained for the case with 15% water content and 0.5% waste tire at 80% relative density.

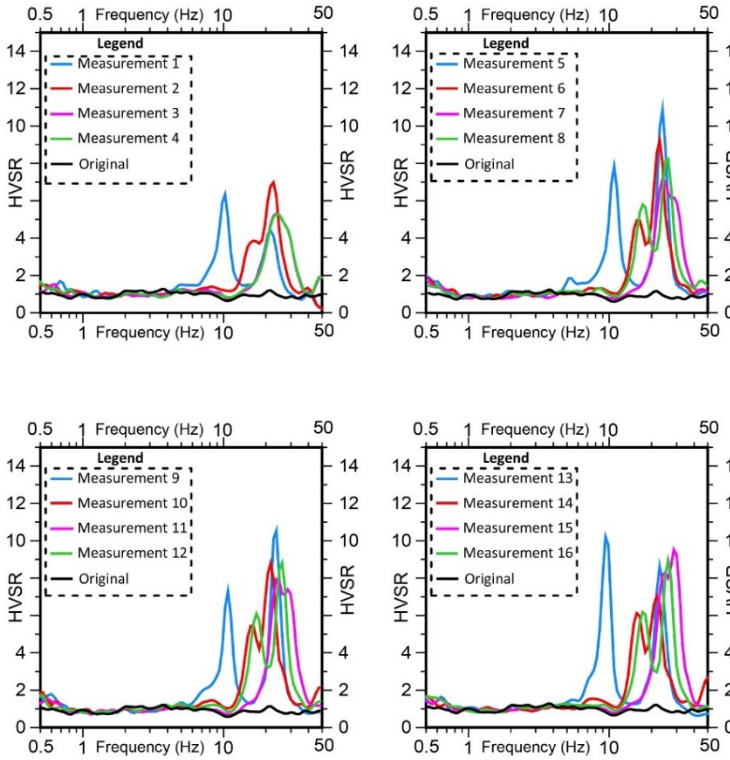
CONCLUSION

In this study, the effects of changes in waste tires, relative density, and water content on the soil dominant frequency and H/V amplitude in sandy soil were investigated experimentally. The soil dominant frequencies generally increased with the waste tire ratio for 0% water content and 60% relative density. An increase in the waste tire ratio increased the soil dominant frequency, whereas it reduced the H/V amplitude in the case of 60% relative density. Except for the case of 2% waste tires, the H/V amplitude increased in general for the case of 80% relative density. The results showed that the most suitable environment for sandy soils in terms of the earthquake–soil relationship was achieved at 60% relative density with 1% waste tires and 80% relative density with 0.5% waste tires. In addition, it is believed that experiments performed based on different relative densities, water contents, and waste rates will provide an important basis for soil engineering studies, particularly those pertaining to sandy soils.

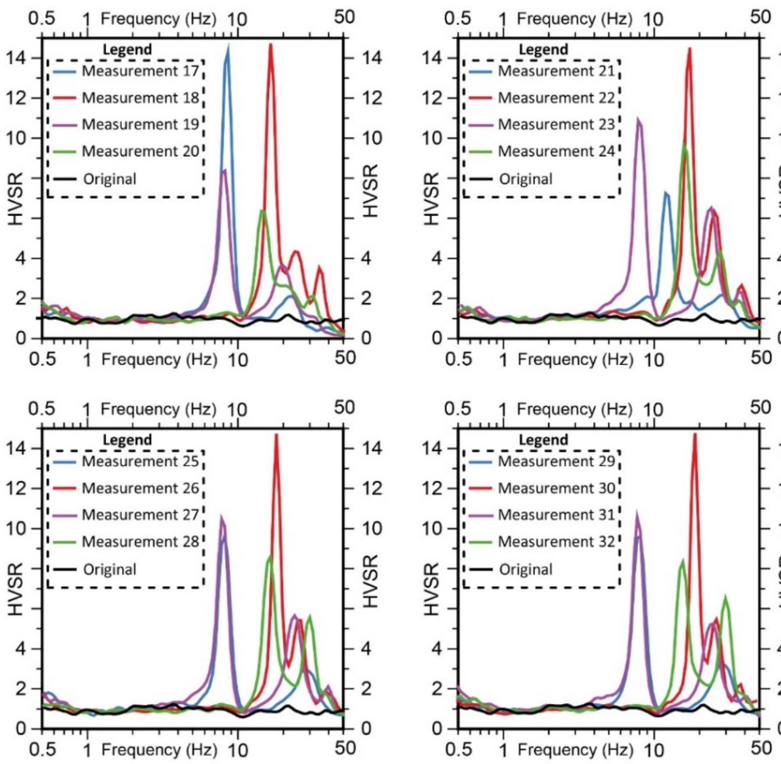
ACKNOWLEDGMENTS

This study is a continuation of the work by Cakici et al. (2019). The experiments were conducted in the Earthquake Research Center Facilities of Ataturk University, Erzurum. A Geopsy code (Wathelet et al. 2020) was used to calculate the soil dominant frequency and the H/V amplitude.

Appendix-1. Graphical representation of microtremor results. Experimental details are provided in Tables 3 and 4 (experiment nos.: 1–16).



Appendix-2. Graphical representation of microtremor results. Experimental details are provided in Tables 3 and 4 (experiment nos: 17–32).



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