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A Study on Single Station Microtremor H/V Spectral Ratio for Detecting the Site Response Characteristics in Torul District of Gümüşhane City, Turkey

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Abstract

Microtremor H/V spectral ratio has gained popularity to assess the dominant frequency of soil sites and local stratigraphy, and to obtain subsoil properties. The aim of this study is to detect the site response characteristics for Torul district of Gümüşhane city, Turkey, by using the ratio of the horizontal to vertical components of Fourier amplitude spectra, designated as H/V spectral ratio model of Nakamura method based on the single station microtremor data analysis. For this purpose, the parameters such as predominant frequency, H/V ratio and predominant period were calculated for 12 measurement points with CMG-6TD three component broad band velocity seismometers and the ground classifications according to predominant periods were made. The predominant period changes between 0.101 and 0.349 sn, and H/V ratio varies from 1.06 to 2.03 for study region. These results show that there are two transient zones (Z_1 and Z_2) between different geologic structures in Torul region.

Key words: Gümüşhane, Microtremor, Nakamura method, site response, predominant period

1. Introduction

There are different methods in order determine the site response characteristics during strong ground motion. Microseisms and microtremors are terms used to define the ambient vibrations of the ground caused by ambient or natural disturbances such as wind, traffic, sea waves, industrial machinery, etc. In practice, they are recorded by using high sensitivity seismometers. The use of measured microtremors in the detection of site response is based on the principle that microtremors spread in the ground and are amplified at periods which are synchronous with the predominant period of the site owing to the properties of selective resonance [1, 2]. Analysis of microtremor data is applied in the recognition of the soil layers, prediction of shear-wave velocity of the ground, and evaluation of the predominant period of the soil during earthquake events. So, after the pioneering study by Kanai [1], it has been suggested that the spectral features of microtremors exhibit some correlation with a site's geological conditions. Measurement and analysis of microtremor data is also an efficient and low-cost method for seismic hazard microzonation. Hence, a lot effort has been made in order to apply the microtremors for determining the site response characteristics for different parts of the world [3, 4, 5, 6, 7, 8, 9]. Microtremors are weak ground motions whose amplitude varies from 1 to 10 μm, and these types of disturbances always exist and are mostly generated by natural processes. Since these variations represent the soil characteristics and these motions change the site effects, microtremor measurements are used to get information about soil vibration properties of sites [10].

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The horizontal to vertical spectral ratio (H/V) method is very useful tool for engineers to quantify the intensity of earthquake ground motion and the capacity of buildings to resist earthquakes [9]. In this context, we applied single station H/V spectral ratio method to determine the predominant frequency and H/V spectral ratio (amplification factor), and to make a classification from predominant period for different parts of Torul district of Gümüşhane city, Turkey.

2. Study Region and Microtremor H/V Spectral Ratio Technique

Gümüşhane is in the northeast part of Turkey and located on the southern zone of the East Pontid tectonic units which takes places in the east of Pontid Orogenic Belt and has generally sedimentary type rocks [11]. The basement rocks of the region consist of Paleozoic-aged metamorphic rocks and Gümüşhane granites rising by cutting them. The Paleozoic period, which is generally known with metamorphic rocks and granites, is evident in the accumulations formations in marine environments during the Mesozoic period. These units deposited in the marine environment consist mainly of volcanic rocks consisting of sedimentary rocks consisting of coal interstratified pebbles, sandstones, limestones, marls and clay stones and andesite, basalt and pyroclastic [11]. Many researchers have stated that these rock assemblages formed during the Jurassic period are deposited in a rift basin extending in an east-west direction. However, the geological structure of Torul district of Gümüşhane city mainly occupied by the Eocene volcanic facies, upper Cretaceous, upper Cretaceous volcanic facies, Cretaceous undifferentiated and upper Cretaceous flysch, Granite and Granodiorite, Quartz-Diorite (from the General Directorate of Mineral Research & Exploration, MTA). Study region and measurement points are given in Figure 1. A total of 12 single-station microtremor measurements were conducted to investigate the site response characteristics of Torul region. For this purpose, a CMG-6TD three component broad band velocity seismometer was used. Measurements were recorded numerically in GCF (Guralp Compressed Format) format with Scream 4.5 program. The locations of the recording points and the distance between the them were chosen as close to the settlement areas, taking into account the size and layout of the survey area. The recording time is determined considering the noise content and it generally changes between 10 and 20 minutes.

Figure 1. Study region and microtremor recording points.

In this study, H/V technique [4] was applied to estimate the site effects. The method has attempted to explain the microtremor with the Rayleigh waves approach, which radiates in a single layered environment over semi-infinite media. As seen in Figure 2, four amplitude spectra are defined in the Fourier frequency domain [4]. Nakamura [4] describes the microtremor movements as a function of frequency as followings:

$$A_S(\omega) = \frac{V_S(\omega)}{V_B(\omega)} \tag{1}$$

$$S_E(\omega) = \frac{H_S(\omega)}{H_B(\omega)} \tag{2}$$

Equation (2) represent the transfer function in observation point. By dividing this transfer function to source effect (Eq. 1), source effect can be removed from measured values. This rate is given as:

$$S_M(\omega) = \frac{S_E(\omega)}{A_S(\omega)} = \frac{\frac{H_S(\omega)}{H_B(\omega)}}{\frac{V_S(\omega)}{V_B(\omega)}} = \frac{H_S(\omega)}{H_B(\omega)} . \frac{V_B(\omega)}{V_S(\omega)} = \frac{H_S(\omega)}{V_S(\omega)} . \frac{V_B(\omega)}{H_B(\omega)} = R_S(\omega) \times R_B(\omega) \tag{3}$$

According to Nakamura [4], H/V spectral ratio, $R_B(\omega)$, is approximately equal to 1 as defined in Equation (4) in the frequency interval of interest (1-20 Hz). Thus, the transfer function given as $R_S(\omega)$ can be obtained from microtremor data recorded at the surface:

$$R_B(\omega) = \frac{V_B(\omega)}{H_B(\omega)} = 1 \tag{4}$$

With the use of Equation (4), the ground effect is defined in terms of the horizontal and vertical components at the surface of motion. In order to reduce the single horizontal component to the two horizontal components recorded as North-South (NS (ω)) and East-West (EW (ω)), the square root mean is taken as given in Equation (5) and H/V spectral ratio which is described in Equation (6) is obtained by dividing vertical component V_S (ω):

$$H_S(\omega) = \sqrt{NS(\omega)^2 + EW(\omega)^2} \tag{5}$$

$$S_M(\omega) = \frac{H_S(\omega)}{V_S(\omega)} \tag{6}$$

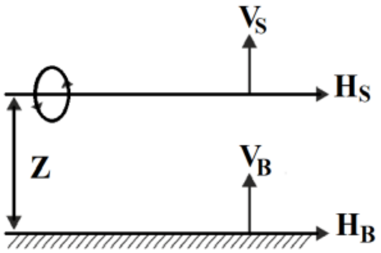

Figure 2. A simple model suggested by Nakamura [4] to explain microtremor records. V_S and H_S are vertical and horizontal components in the surface, V_B and H_B are vertical and horizontal components in Z depth.

The processing of H/V data was carried out using the GEOPSY software, an open source software for geophysical research and applications [12, 13]. Figure 3 shows a flowchart of the stages involved in applying the H/V ratio technique to each horizontal and vertical window to derive the desired spectrum [8]. After the trend effect of microtremor data was removed, the data were filtered with a band-pass Butterworth filter between 0.5 and 20 Hz. The corrected signals were windowed in 20 second lengths. Over each resulting window, a Cosine tapper filter with 10% overlap was applied to reduce border effects due to the cutting process. For each window, fast Fourier transform (FFT) factor was calculated to convert the signal from time domain to frequency domain. The resulting spectrum of each window was smoothed, using the procedure described by Konno and Ohmachi [14], to remove the small oscillations (noise) from the obtained spectrum.

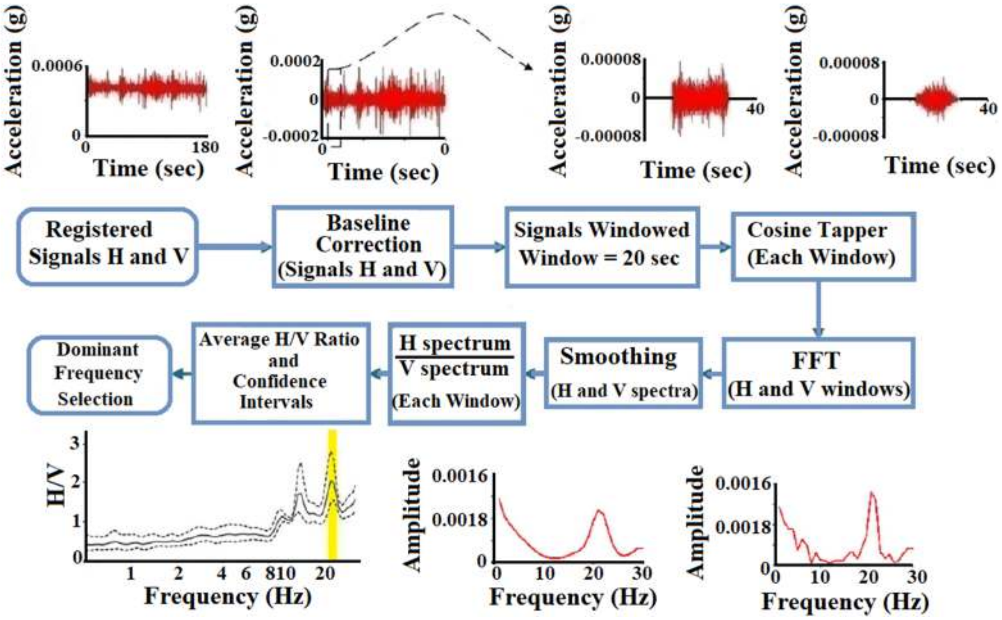

Figure 3. A schematic diagram of stages for obtaining microtremor H/V spectral ratio. The graphics above and below the diagram boxes show the samples of different stages (modified from Rincon et al., [8]).

3. Results and Discussions

The predominant frequency values were determined based on an H/V spectral ratio analysis of single station microtremor measurements obtained at 12 points in Torul district of Gümüşhane city, Turkey. The results were interpreted by using the peak values in the H/V spectral ratios obtained from the microtremor measurements. Figures 4, 5, 6 and 7 show the microtremor records for the points given in Figure 1 and H/V spectral ratio curves with their peaks. These peaks are temporally and spatially stable and can be thought as a fundamental (resonance) frequency of the region [15]. Predominant frequency values for all study region changes between 2.858 Hz and 9.838 Hz, and H/V spectral ratio values vary from 1.06 to 2.03. By using these values, predominant period values were calculated between 0.101 sn and 0.349 sn for different 12 points in Torul region. Also, regional changes of predominant frequency and H/V ratio, and the map of site effect classification according to predominant period were shown in Figure 8. These results can be used to identify small-scale seismic risks and prepare detailed data for seismic microzonation in this urban region.

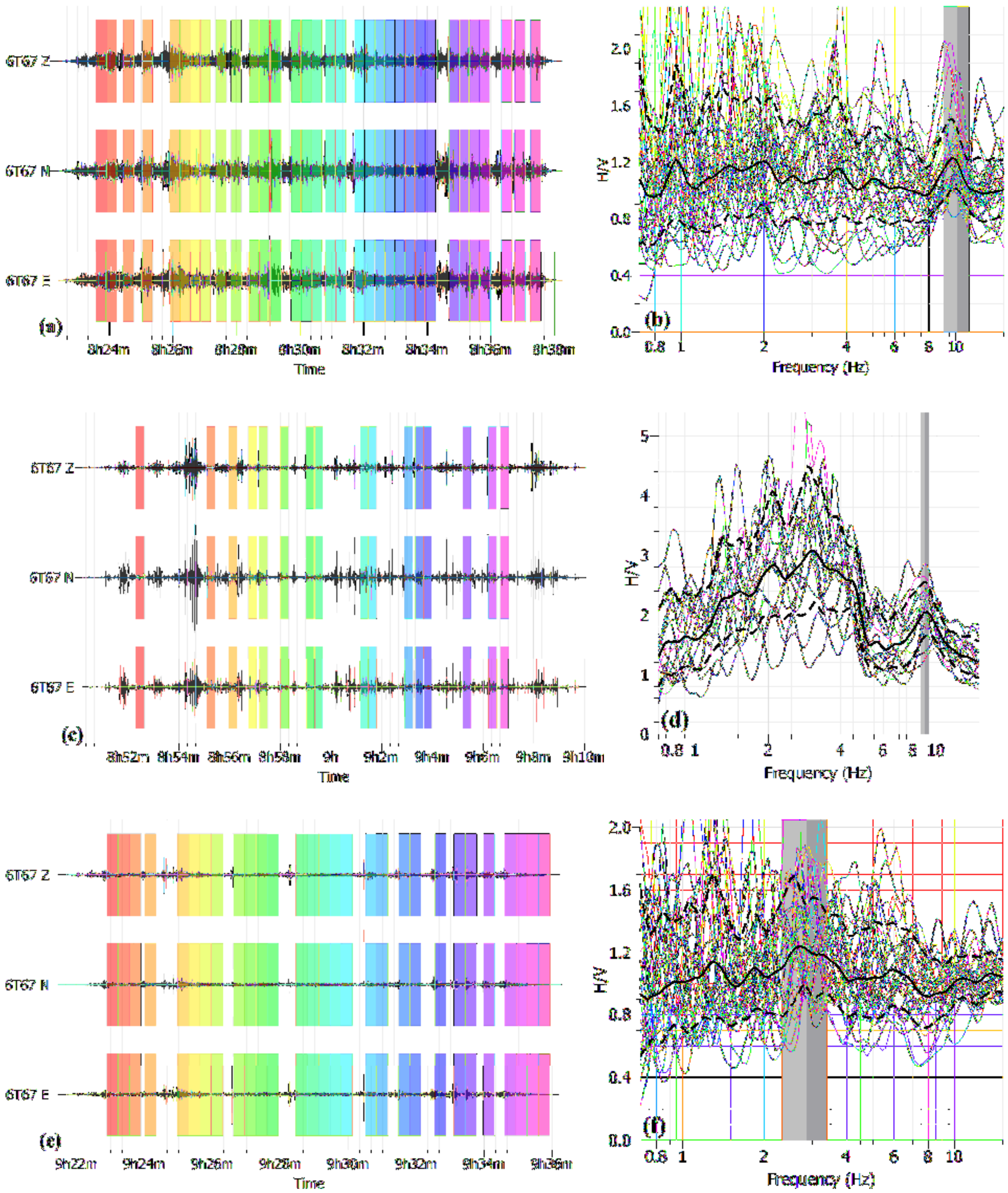

Figure 4. a) Three components microtremor data and resolution windows on microtremor record for TR1 point, **b)** H/V spectral ratio curves and interpretation (average H/V) for TR1 point, **c)** Three components microtremor data and resolution windows on microtremor record for TR2 point, **d)** H/V spectral ratio curves and interpretation for TR2 point, **e)** Three components microtremor data and resolution windows on microtremor record for TR3 point, **f)** H/V spectral ratio curves and interpretation for TR3 point. Straight black lines and dashed black lines on Figures (b,) (d) and (f) represent the H/V ratio and standard deviation, respectively.

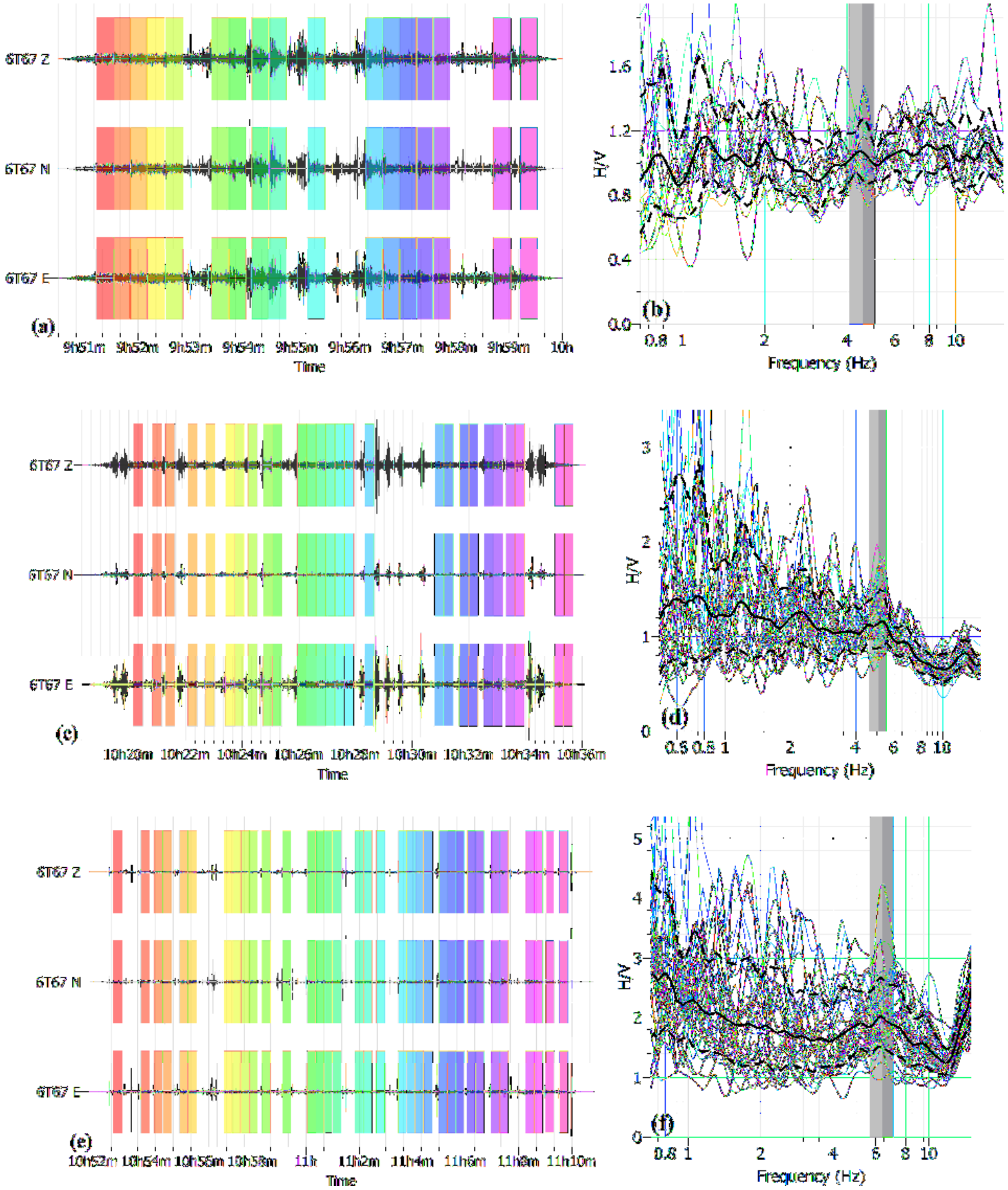

Figure 5. a) Three components microtremor data and resolution windows on microtremor record for TR4 point, **b)** H/V spectral ratio curves and interpretation (average H/V) for TR4 point, **c)** Three components microtremor data and resolution windows on microtremor record for TR5 point, **d)** H/V spectral ratio curves and interpretation for TR5 point, **e)** Three components microtremor data and resolution windows on microtremor record for TR6 point, **f)** H/V spectral ratio curves and interpretation for TR6 point. Straight black lines and dashed black lines on Figures (b,) (d) and (f) represent the H/V ratio and standard deviation, respectively.

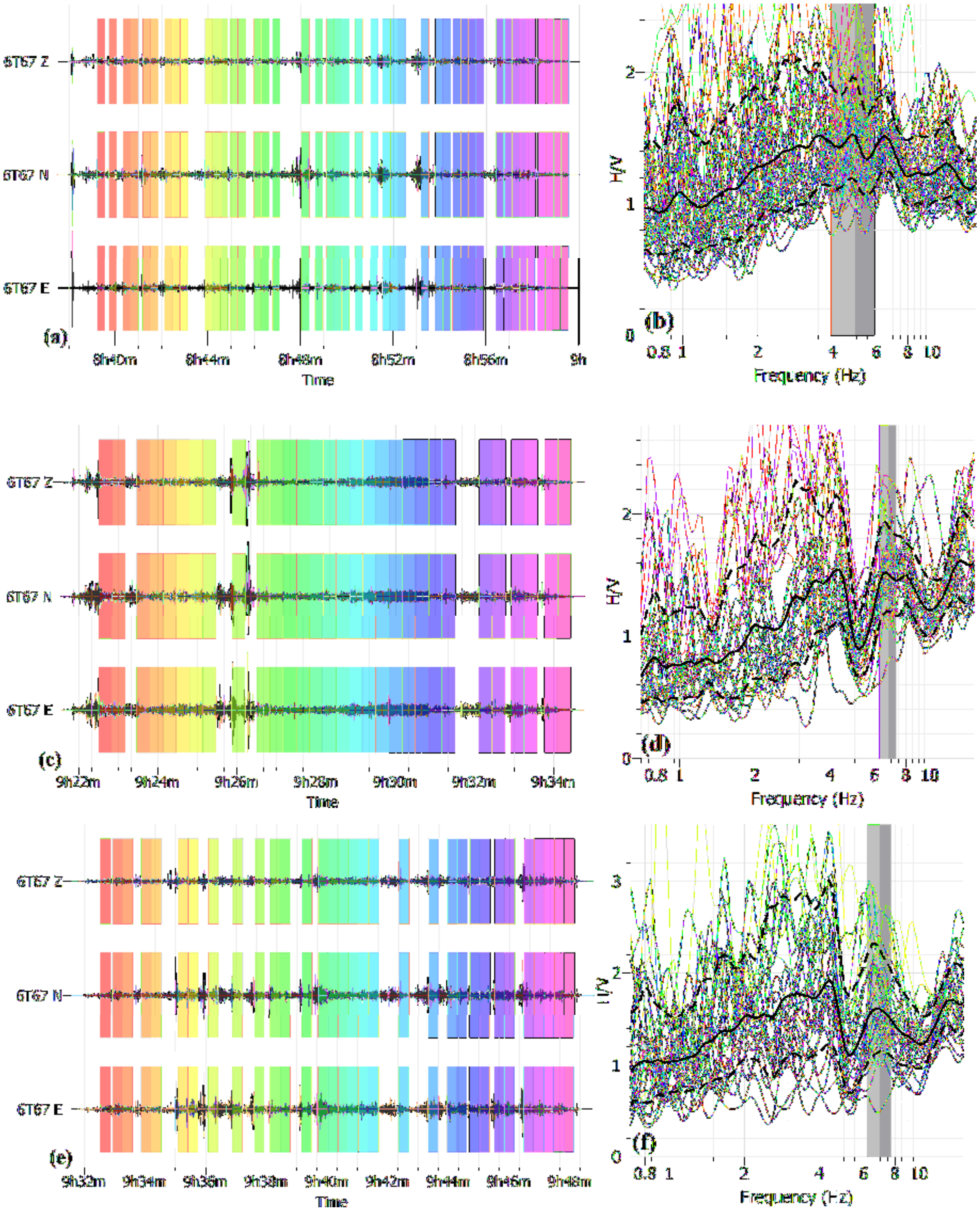

Figure 6. a) Three components microtremor data and resolution windows on microtremor record for TR7 point, **b)** H/V spectral ratio curves and interpretation (average H/V) for TR7 point, **c)** Three components microtremor data and resolution windows on microtremor record for TR8 point, **d)** H/V spectral ratio curves and interpretation for TR8 point, **e)** Three components microtremor data and resolution windows on microtremor record for TR9 point, **f)** H/V spectral ratio curves and interpretation for TR9 point. Straight black lines and dashed black lines on Figures (b,) (d) and (f) represent the H/V ratio and standard deviation, respectively.

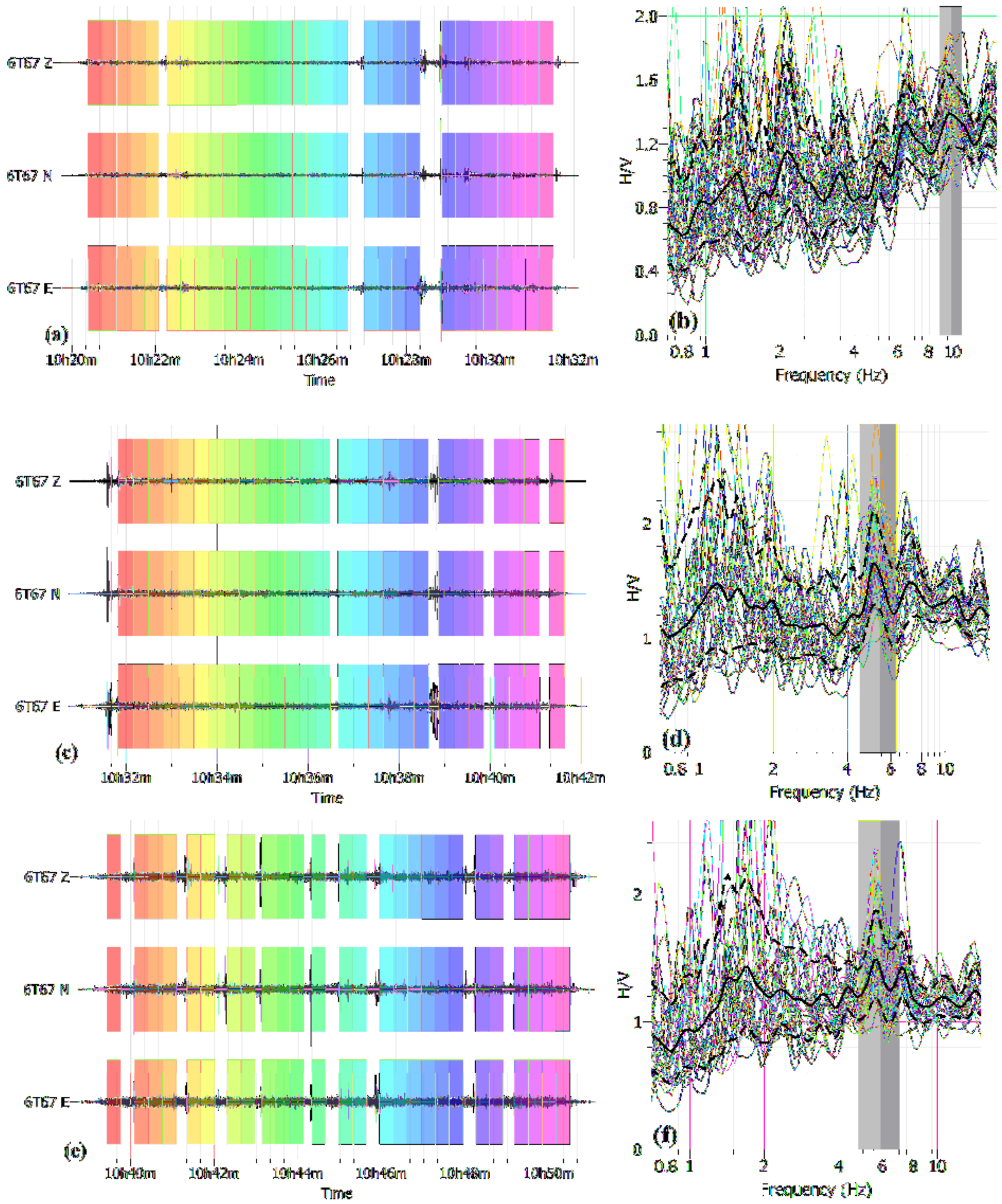

Figure 7. a) Three components microtremor data and resolution windows on microtremor record for TR10 point, **b)** H/V spectral ratio curves and interpretation (average H/V) for TR10 point, **c)** Three components microtremor data and resolution windows on microtremor record for TR11 point, **d)** H/V spectral ratio curves and interpretation for TR11 point, **e)** Three components microtremor data and resolution windows on microtremor record for TR12 point, **f)** H/V spectral ratio curves and interpretation for TR12 point. Straight black lines and dashed black lines on Figures (b,) (d) and (f) represent the H/V ratio and standard deviation, respectively.

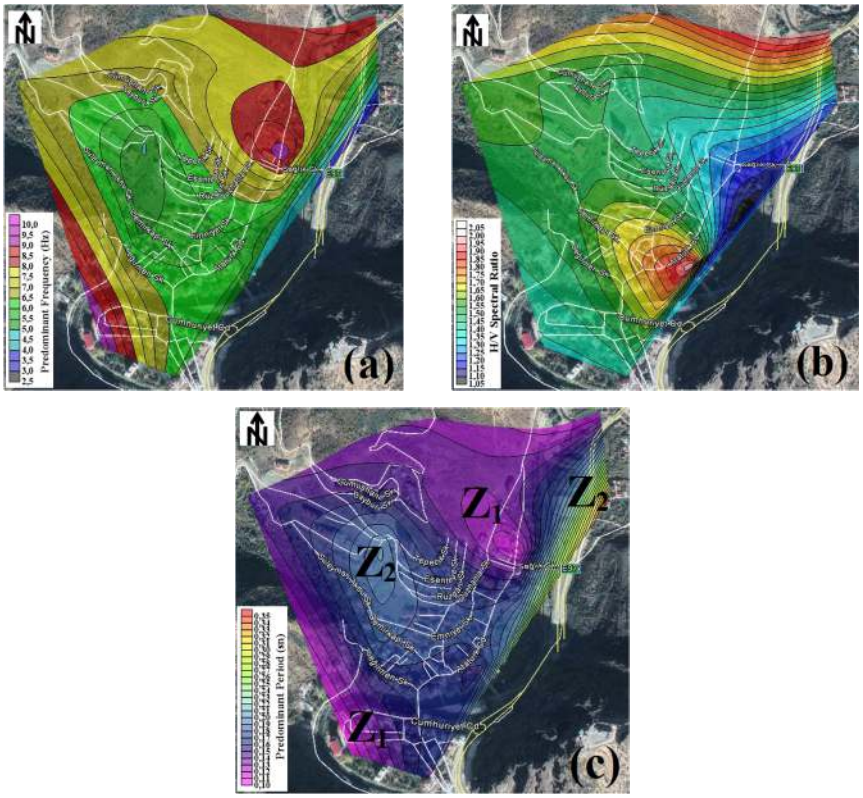

Figure 8. a) Predominant frequency map, **b)** H/V spectral ratio map, **c)** Site effect classification according to predominant period for Torul district of Gümüşhane city.

For the evaluation of predominant periods of the soil, the Nakamura [4] method has been widely used. Kanai and Tanaka [3] stated that the changes in microtremor periods depends on the subsoil type. A relatively sharp peak may be seen around 0.1-0.6 sn if we have a simple stratified soil. However, more than two peaks may appear, one smaller near 0.2 sn and one large near 1.0 sn, if soil type is mixed. One can see a sharp peak between 0.1 and 0.2 sn (Z_1) on a mountain whereas this peak can be seen between 0.2 and 0.4 sn (Z_2) for firm diluvial soil. For soft alluvial soil, some peaks can be seen between 0.4 and 0.8 sn (Z_3). Also, especially on soft soils the curves are flat and change between 0.05 and 0.1 sn or between 1.0 and 2.0 sn (Z_4). According to these site effect classifications by Kanai and Tanaka [3], also as seen in Figure 8c, we can propose two transient zones (Z_1 and Z_2) in Torul region consisting of hard rock composed of gravel, sand and other soils mainly consisting of tertiary or older layers, hard sandy clay, sandy gravel, loam or sandy alluvial deposits whose depths are 5m or greater.

Conclusions

Analysis of microtremor data can be applied in the identification of the soil layers, prediction of shear-wave velocity of the ground, and evaluation of the predominant period of the soil during earthquakes. This study focused on the classifications of the site effect by using the H/V spectral ratio model of Nakamura technique based on the single station microtremor data analysis. In this context, predominant frequency, H/V spectral ratio and predominant period were determined and site effect classifications according to predominant periods were made for 12 observation points in

Torul district of Gümüşhane city, Turkey. H/V spectral ratio changes between 1.06 and 2.03, the predominant frequency varies from 2.858 to 9.838 Hz, and the predominant period are calculated between 0.101 and 0.349. The results show that predominant periods varies in relation to the soil formation and two transient zones can be proposed as Z_1 and Z_2 between different geologic structures in Torul region. Correlations that were performed between the predominant period and surface geology gave the promising outcomes. As an important result, a detailed and comprehensive survey with microtremor measurements could be one of the useful methods for seismic microzonation and disaster mitigation, even when detailed soil profile data is not available.

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