In this study, an attempt was made to estimate the ground types for Torul, Kürtün, Kelkit, Şiran and Köse districts of Gümüşhane, Turkey, by analyzing the predominant frequency and H/V ratio from microtremor data through the single station microtremor H/V ratio of Nakamura technique. For all districts, predominant frequencies show a general distribution between 1.36 and 9.84 Hz, H/V ratios between 1.01 and 9.58. According to these variations, three transient zones can be suggested as

i) \( Z_1 \), stiff rock composed of gravel, sand and other soils mainly consisting of tertiary or older layers with period of 0.1 to 0.2s,

ii) \( Z_2 \), sandy gravel, stiff sandy clay, loam or sandy alluvial deposits whose depths are 5m or greater with period of 0.2 to 0.4s, and

iii) \( Z_3 \), standard grounds other than type \( Z_1 \), \( Z_2 \) or \( Z_4 \) (alluvial deposits whose depths are 5m or greater) with period of 0.4 to 0.8s. These results suggest that predominant period obtained from predominant frequency shows significant changes based on the soil formation, and H/V ratio highly corresponds to these subsurface properties. Soil-structure interaction can also be evaluated by considering these results and possible resonance risk can be investigated for building resonant frequency in these residential districts in the next. Thus, this type of application and evaluation of microtremor data may provide primary and useful information for other geophysical, geological and geotechnical studies such as planning the seismic resistant infrastructure, detecting the small-scale seismic risks and making a suitable and reliable seismic hazard microzonation in Gümüşhane.

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INTRODUCTION

There are various techniques that have been used in order to identify the subsoil characteristics during the strong ground motions. One of the most widely applied techniques to estimate the ground types is the microtremor horizontal to vertical (H/V) ratio. This technique was defined by Nakamura [1] in relation to borehole explorations and analysis of strong ground motion data on the different geological structures. Many researchers have used the spectral features of microtremors to estimate the predominant or natural frequency of the soil in Turkey and different sites of the world. These studies suggest a good relationship between the surface geology and the spectral ratios of microtremors [1–11]. These results show that microtremors are very suitable tools in the identification of surface geological effects on the seismic motion without detailed geology.

Microtremors are always exist and known as weak ground motions based on the natural or ambient processes such as earthquakes, sea waves, wind, rivers, rain, traffic, tides, changes in atmospheric pressure, human activities, machinery, etc. Their amplitudes vary from 0.1 to 1.0 μm, periods between 0.05 and 2.0s, and these motions change the site effects [11–13]. Observations and assessments of microtremor data have some advantages over other techniques for site response characteristics due to its simplicity, inexpensive, ease of use, minimum computational time, short duration for measurements and data process [2,6]. General applications of microtremor studies can be carried out: (i) to calculate the amplification of horizontal movements in the free surface throughout earthquakes, (ii) to measure background seismic noise and to estimate the mechanical features of the earth’s subsurface, (iii) to determine the site response characteristics, (iv) to detect the subsoil types, (v) to estimate the shear wave velocity of the ground, (vi) to detect the effect of site conditions on damage distribution during the earthquakes, (vii) to estimate the predominant resonant frequency and period of the sediments, (viii) to design the seismic resistant infrastructure, (ix) to identify small-scale seismic risks and to make a convenient and reliable seismic hazard microzonation in urban areas [14–17].

The H/V spectral ratio of recorded microtremors can be estimated from ambient noise records and this technique is quite practical tool for engineers to measure the intensity of earthquake ground motion and the capacity of buildings to resist earthquakes [6]. For this purpose, we used the single station microtremor H/V spectral ratio technique in this study and aimed to investigate the seismic site response characteristics in Torul, Kürütün, Kelkit, Şiran and Köse districts of Gümüşhane province, Turkey. For this purpose, we determined the predominant frequency and H/V ratio (H/V amplitude spectrum or HVSR amplitude) of subsurface ground using measured microtremor data. Thus, a classification for ground types in different districts of Gümüşhane was made based on the single station microtremor data analysis.

SURFACE GEOLOGY AND SEISMOTECTONICS OF GÜMÜŞHANE

The Gümüşhane is located in the eastern part of the Pontide Orogenic belt in the northeast Turkey. The principal base rocks observed in Gümüşhane and vicinity are composed of the Palaeozoic-aged metamorphic rocks and Gümüşhane granites which rise by cutting these metamorphic rocks (One can find many details on geological ages in Taş et al., [18]). Surface geology in and around Gümüşhane is modified from the database of the General Directorate of Mineral Research and Exploration (MTA, URL-1) and given in Figure 1. Granitic formations are dominated in Gümüşhane city center and the main geological units close to the city center are formed of granite, granodiorite and quartz-diorite, Eocene-volcanic facies, undifferentiated Cretaceous, upper Cretaceous and Flysch. Torul district and surrounding area are generally covered with granite, granodiorite, quartz-diorite and Eocene-volcanic facies. The principal surface geology in Kürütün district and vicinity includes granite, granodiorite, quartz-diorite and upper Cretaceous-Volcanic facies. Geological formations of undifferentiated Eocene, Eocene flysch, mid-Eocene lutetian, andesite-splitle-porphryite, basalt-dolerite, rhyolite-dacite and volcanic tuff-agglomerate-breccia are dominant in and around Şiran district. However, Kelkit and Köse districts are composed of the Pleistocene and Holocene-Recent structures, undifferentiated Neogene continental formations, undifferentiated Eocene, Eocene flysch, mid-Eocene lutetian floors and partially granite, granodiorite, quartz-diorite structures.

The major factors that affect the current seismo-tectonic situation of Gümüşhane and vicinity are fracture systems and fold tectonics. Tectonic structures of Gümüşhane and vicinity were compiled from Şaroğlu et al. [19] and Bozkurt [20] and were shown in Figure 2. There are several fault segments, zones and basins located close to Köse, Kelkit, Şiran, Erzincan and Bayburt, and these tectonic structures are generally related to the NAFZ. As seen in Figure 2, these active systems can be given as Kelkit-Çoruh Fault Zone (KÇFZ), Bayburt Basin (BYB), Kelkit Basin (KLB), Kelkit Fault Segment (KLFS), Akdağ-Çayırlı Fault Zone (ACFZ), Dağyolu Fault (DYF) and Tercan-Askale Fault Zone (TAFZ). KÇFZ is about 600 km long and has a left lateral strike slip fault mechanism. This zone has four segments from the southwest to the northeast: Kelkit, Çoruh, Posof and Borjomi-Kasbeg. KLFS is separated from the NAFZ with a length of about 100 km. This segment is divided into two branches around Kelkit and results in a basin [18]. TAFZ has a left lateral strike slip fault mechanism. It has a length of about 150 km and a wide of 2 to 4 km. This fault zone passes through the western part of Erzurum near the...
NAFZ and includes several parallel fault segments which has a length between 2 and 20 km [20].

Gümüşhane is a very close residential area to the North Anatolian Fault Zone (NAFZ), about 80 km, and due to the proximity to the NAFZ, a strong or large earthquake on the NAFZ and surrounding area may affect this region. Especially, high-rise buildings constructed on alluvial grounds in creek beds along the Harşit stream will be affected from a possible large and/or destructive earthquakes which may occur on the NAFZ [21]. During the instrumental (past 48 years in this study) and historical periods, there are two strong events around Gümüşhane border as seen in Figure 2: January 19, 1979 (M₃ 5.0) and August 12, 1985 (M₃ 5.0) earthquakes (M₃ is duration magnitude). Also, several large and destructive earthquakes occurred in and around the NAFZ between 1970 and mid-2018 such as March 13, 1992 (M₃ 6.5) and March 15, 1992 (M₃ 5.3), whereas the other great events occurred in some parts of Gümüşhane near the NAFZ. Figure 2 shows the epicenter distributions of earthquakes (depth ≤ 75 km) with 1.0 ≤ M ≤ 6.5 from 1970 to middle of 2018.
METHODOLOGIES AND MICROTREMOR DATA FOR STUDY REGIONS

The H/V Spectral Ratio Method

Microtremor H/V spectral ratio technique was developed by Nakamura [1] on the different geological ground circumstances related to the borehole surveys by using the analyses of strong ground motion. Nakamura [1] supposed that vertical component of the ambient noise at the ground surface includes the properties of basement ground. Therefore, Rayleigh waves on the sedimentary rock influence the vertical component and thus, vertical component can be utilized to eliminate both of the source and Rayleigh wave effects from horizontal components [22]. In fact, the first of all, the H/V spectral ratio was provided with the strong motion measurements at different parts of Japan. Then, many researchers mentioned above showed that microtremor H/V spectral ratio of ambient noise may be utilized to describe the predominant frequency and H/V ratio of different ground structures in different regions of the world. Nakamura [1] assumes that microtremors mainly contain the shear waves, and the layer of soft soil does not magnify the vertical waves. The horizontal components of the shear waves are magnified by soft soil layer because of the multiple reflection of the waves [13]. There are four amplitude spectra described in the Fourier frequency domain. Nakamura [1] suggested that the H/V spectral ratio of the Fourier amplitude spectra of microtremors can be used to estimate the transfer function of the surface layers. Microtremor movements were described as a function of frequency:

\[ A_s(\omega) = \frac{V_s(\omega)}{V_g(\omega)} \]

\[ S_f(\omega) = \frac{H_v(\omega)}{H_h(\omega)} \]  

where \( V_s(\omega) \) is the vertical component of the movement on the surface and \( V_g(\omega) \) is the vertical component of the movement on the substrate of the surface layer. Equation (2) represents the transfer function in measurement point. In this equation, \( H_h(\omega) \) is the horizontal component on the surface and \( H_v(\omega) \) is the horizontal component of the movement on the substrate of the surface layer. Source effect can be removed from observation values by dividing transfer function given in Equation (2) to source effect given in Equation (1). This rate is defined as:

\[ S_h(\omega) = \frac{S_f(\omega)}{A_s(\omega)} = \frac{H_v(\omega)}{V_g(\omega)} \frac{H_h(\omega)}{V_s(\omega)} = \frac{H_v(\omega)}{V_s(\omega)} \frac{V_s(\omega)}{H_v(\omega)} = \frac{H_v(\omega)}{V_s(\omega)} = \frac{H_v(\omega)}{V_s(\omega)} \frac{V_s(\omega)}{H_v(\omega)} = R_s(\omega) \times R_f(\omega) \]

Nakamura [1] stated that the H/V spectral ratio, \( R_s(\omega) \), taken in bedrock in the frequency range of interest (1–20 Hz) for engineering purposes studies, is approximately equal to 1 as given in Equation (4). In this way, the transfer function described as \( R_s(\omega) \) can be obtained from microtremor data measured at the surface:

\[ R_s(\omega) = \frac{V_s(\omega)}{H_s(\omega)} = 1 \]

Two horizontal components recorded as north-south, NS (\( \omega \)), and east-west, EW (\( \omega \)), can be combined as a single component taking the magnitude of the vector as described in Equation (5):

\[ H_v(\omega) = \sqrt{NS(\omega)^2 + EW(\omega)^2} \]

The ground effect is described in terms of the horizontal and vertical components at the surface. The H/V spectral ratio can be obtained by dividing horizontal component, \( H_v(\omega) \), to vertical component, \( V_s(\omega) \), as described in Equation (6):

\[ S_h(\omega) = \frac{H_v(\omega)}{V_s(\omega)} \]

Evaluation of the H/V ratio was achieved by using the GEOPSY software developed within the framework of the Site Effects Assessment using Ambient Excitation (SESAME) Project [23]. The first step involved in applying the H/V spectral ratio technique, recorded signals were fixed with a baseline correction and trend effects in the data were removed. Then, corrected records were filtered with a Butterworth band pass filter with a range of 0.5–20 Hz.

In the third stage, several window lengths in the range of 10–40s were tested to find the suitable window size and a 20s time window length was preferred. For each window, a Cosine taper filter with 10% width was implemented to decrease border effects caused by the cutting operation. In this way, the noise at very low and high frequencies compared to the signals was removed, and only the frequency content of the microtremors remain. In the next step, the fast Fourier transform (FFT) was utilized to calculate the three component (north-south, east-west and vertical) amplitude spectrum. For each window, the signal in the time domain was converted to frequency domain. In order to smooth the computed spectrum, a smoothing type filter defined by Konno and Ohmachi [24] was used with constant number of 40. In this way, the small noises from the resulting spectrum were removed and a good approximation with clear spectrum peaks was generated by this smoothing coefficient. In the next stage, the root mean square of spectrum values for two horizontal components (north-south and east-west) was taken and the single horizontal component
individual site. A total of 180 single station microtremor measurements were conducted to estimate the predominant frequency and H/V ratio. For this purpose, GURALP CMG-6TD three component broad band velocity seismometer was used. Measurements were recorded numerically in GCF (Guralp Compressed Format) with Scream 4.5 program. The locations of the recording points and the distance between them were chosen as close to the settlement areas, taking into account the size and layout of the survey area. Distances between microtremor measurement points range from 100 to 500 m depending on the density of the settlement area. The recording time was determined by considering the content of the noise and generally varies from 10 to 30 minutes. Thus, the transfer function (H/V spectral ratio) of surface layer as described by Equation (6) was estimated only from the tremor on the surface. This ratio between vertical and horizontal components of the measured at the surface is defined the site effects as $S_M(\omega)$. This mean that H/V ratio can be used a reliable application of the site response to shear wave, supplying reliable results, not only for the resonance frequency, but also for the corresponding amplification [7].

was obtained. Thus, horizontal component direction was computed independently and the noise ratio on any of components was reduced. In the final step, the average of horizontal components (root mean square) was divided by the vertical component spectrum for all windows, and an average spectrum was computed with its confidence intervals to estimate the resonant frequency with respect to high amplitude peak. The H/V spectral ratio for suitable windows was obtained and then, the average of the spectra was accepted as the H/V spectral ratio for each measurement point. Representative H/V spectral ratio curves were plotted for each measurement point according to the standard criteria of SESAME [23]. As a result, the peak frequency of the H/V spectrum plot gives the dominant frequency and H/V ratio of the measured point. Figure 3 shows all these data processing steps with an example measurement point from Köse district.

Study regions and measurement points for Torul, Kürtün, Kelkit, Şiran and Köse districts of Gümüşhane province were shown in Figure 4. Measurement points were placed on “Google Earth” in order to obtain the best images of the point and to see the settlements in each individual site. A total of 180 single station microtremor measurements were conducted to estimate the predominant frequency and H/V ratio. For this purpose, GURALP CMG-6TD three component broad band velocity seismometer was used. Measurements were recorded numerically in GCF (Guralp Compressed Format) with Scream 4.5 program. The locations of the recording points and the distance between them were chosen as close to the settlement areas, taking into account the size and layout of the survey area. Distances between microtremor measurement points range from 100 to 500 m depending on the density of the settlement area. The recording time was determined by considering the content of the noise and generally varies from 10 to 30 minutes. Thus, the transfer function (H/V spectral ratio) of surface layer as described by Equation (6) was estimated only from the tremor on the surface. This ratio between vertical and horizontal components of the measured at the surface is defined the site effects as $S_M(\omega)$. This mean that H/V ratio can be used a reliable application of the site response to shear wave, supplying reliable results, not only for the resonance frequency, but also for the corresponding amplification [7].

![Figure 3. Data processing steps for the H/V spectral ratio calculations. These processes were applied all measurement points in study region. This example includes KS38 point: (a) raw microtremor data, (b) analysis window (number of windows: 63, length=20s), (c) average spectrums of three components and (d) H/V spectral ratio of each window (color lines), mean H/V ratio spectrum (black line) and standard deviation (dashed line).](image-url)
Kg-value (seismic vulnerability index) Estimation from H/V Spectral Ratio

In recent years, a lot of studies have been achieved to define the liquefaction potential (weak points) of a soil and to estimate the damage/strain of buildings and ground during a strong/large earthquake by using vulnerability index (Kg-value) estimated from microtremor data [9,10,13,15]. Kg-value can be estimated by using the amplification factor (H/V ratio) and the predominant frequency obtained from microtremor measurement as following [9,10]:

\[
Kg = \frac{A_g^2}{F_g}
\]  

(7)

where \(A_g\) is the amplification factor and \(F_g\) is the predominant frequency. It is suggested that soil is susceptible to large deformation if \(Kg\)-value is over 20.0 and the regions in which have a value larger than 10 can be considered as the locations in risk, whereas \(Kg\)-values are very low in undamaged/risk-free regions [9,10]. It is possible to appraise the vulnerability of a point-based site under strong ground motion. Kg-value can be calculated for both soil and structures since it is related to the natural vibration period and amplification factor [9]. Thus, Kg-value is a parameter depending on the dynamic properties of soil and weak/strong regions can be defined by using this value for study areas and damage probability can be estimated.

RESULTS AND DISCUSSIONS

Previous studies show that two important site response characteristics (predominant frequency and amplification factor) can be estimated safely. Therefore, we used the single station microtremor data in order to identify the ground type characteristics for Torul, Kurttun, Kelkit, Shiran and Köse districts of Gümüşhane. Single station microtremor data was recorded at 12 points in Torul, 9 points in Kurttun, 48 points in Kelkit, 60 points in Shiran and 51 points in Köse. Since the site conditions were more suitable in Kelkit, Shiran and Köse, more measurements were taken in these districts. Thus, predominant frequencies and H/V ratios were obtained for each measurement points in all districts. Three components microtremor signals with resolution windows on microtremor records and the H/V spectral ratio curves with average H/V for selected points of TR7, K3, KL9, SR27.
and KS38 were given as the representative examples for each region. These randomly selected examples were plotted in Figure 5. The obtained spectra include the standard deviations for all the H/V curves and the standard deviations were plotted by two dashed lines above and below of the H/V curves. All estimated values from these H/V curves as well as the other information of the points were also given in Tables 1 to 5. These selected figures show the final data processing steps (defined above) that was applied to all the microtremor measurements in the study region. These sequences of data processing implemented in the representative samples includes the interpretation of H/V curves. In these context, these primary and essential steps were involved in all the recorded microtremor data (not shown for all 180 points, only 5 measurements) in the study area. When considered the largest amplitudes of spectrum, the predominant peak in the H/V spectral rate is much more evident as a single peak with the maximum amplitude in some points (limp grounds with soft padding). However, the maximum amplitude in some points is shown in high frequencies as the multiple peaks (solid grounds). It is stated that the H/V ratios exhibit a clear peak in a soft soil structure underlying a hard rock and these peaks are constant in space and time [12]. Therefore, these peaks can be thought as predominant frequencies of the region. However, a second peak value can be observed in most of microtremor measurements. The peak with maximum amplitude can be false peak in the H/V curves with multiple peaks. In this situation, the frequencies estimated in the H/V graphics can be too small or too large to be expected according to the existing ground type. When examined all the values given in Tables, the maximum frequency estimated from horizontal amplitude spectrum on the H/V spectral rate curves is around 10 Hz and these results are accordance with the vertical amplitude spectrum values. For this reason, all the results were calculated by using the peak values (there are not multiple peaks in our data) in the H/V ratios. The H/V ratios were analyzed according to the SESAME [23] reliability criteria. It was seen that all results were generally found to provide reliable H/V curve criteria. However, unreliable H/V ratios were not included in the evaluations. Thus, the spectral amplitudes of Torul, Kürtün, Kelkit, Şiran and Köse were estimated on the maximum peaks which are compatible with the ground structure they were measured.

As mentioned above, this study aims to contribute to the classification of the ground types from microtremor data for different districts of Gümüşhane province of Turkey. The analyses of microtremor measurements in different parts of

Figure 5. Examples of the H/V spectral ratio curves (solid black lines) and their standard deviations (dashed black lines) from different measurement points for: (a) TR7, (b) K3, (c) KL9, (d) SR27 and (e) KS38, respectively. Examples from each district were selected as randomly.
the world show that obtained results are useful to define the subsurface soil profiles and to build the earthquake-resistant design. The principal subject in the geotechnical researches and in detecting of the site response properties is to define the subsoil types. There are a large number of studies such as Nogoshi and Igarashi [25] and Panah et al. [26] for the ground type classifications. Nogoshi and Igarashi (1970) suggested a general classifications of ground types for Hakodate City in Hokkaido, and Panah et al. [26] proposed a classification based on the H/V spectral ratio technique in eastern and central Iran. Predominant frequencies were used in both studies as a main factor, and these works are based on the dynamic subsurface properties such as frequency, amplification, period, alluvial thickness etc. In addition to these studies, Kanai and Tanaka [11] stated that the changes in microtremor periods are related to the subsoil type. They proposed that a relatively strong peak is recorded between the periods 0.1 and 0.6s if there is a simple stratified subsurface ground. However, if subsoil properties are complicated, more than two peaks can come in sight, which one of them is small around 0.2s and the other is large around 1.0s. A sharp peak can be seen between 0.1 and 0.2s (Z₁ subsoil type) on a mountain whereas this peak can be recorded between 0.2 and 0.4s (Z₂ subsoil type) for hard diluvial formation. In some records, the curves do not have regular shapes and several peaks can appear between 0.4 and 0.8s (Z₃ subsoil type) on soft alluvial soils. In addition to these soil types, some peaks vary from 0.05 to 0.1s and from 1.0 to 2.0s (Z₄ subsoil type) especially on soft soils. Thus, Kanai and Tanaka [11] suggested that microtremor amplitudes increase at ground surface in these periods. Since Nakamura [1] technique has been widely used for the evaluation of predominant periods of the soil, we preferred this model in order to identify the ground type classifications for the study region. These classifications by Kanai and Tanaka [11] were given in detailed in Table 6.

H/V ratios give information about the stability of ground and are inversely proportional to strength of the measured area. Wave amplitude propagating in a limp ground grows in proportion to the weakness of the medium. Great H/V ratios can be obtained if the medium is weak, whereas small H/V ratios can be observed if the medium is strong [27]. However, a region with large H/V ratio cannot be said to have a limp structure and it should be supported with different techniques to confirm this result. When examining the H/V ratios given in Tables 1 to 5 and the regional variation maps plotted in Figures 6 to 10, H/V ratios are generally seen to be inversely proportional with subsoil types. In general, the largest H/V ratios were calculated for Z₁ class and the smaller values were obtained for Z₂ and Z₃ classes. Therefore, the regions including sandy gravel, stiff sandy clay, loam or sandy alluvial deposits whose depths are 5m or greater will further enlarge the ground response compared to the other environments such as stiff rock composed of gravel, sand and other soils mostly consisting of tertiary or older layers. Considering all the study regions, the H/V ratios can be said to be consistent with the ground on which they were measured (Tables 1–5). Considering the importance in microzonat studies, it is obvious that the calculated H/V ratios and regional variation maps for different districts of Gümüşhane can provide contribution to knowledge in establishing the reliable ground-structure interaction, to settlement planning and to determine the safe areas.

As in the H/V ratios, the predominant frequency (or predominant period) values also provide information about the weakness and stability of the medium. Detailed information of total 180 single station microtremor measurements was given in Tables 1 to 5, respectively. As seen in Tables 1 to 5, predominant frequency values vary from 1.27 to 9.83 Hz and H/V ratios from 1.01 to 9.58 for all districts. Regional changes maps of these three desired parameters for all study regions were also given in Figures 6 to 10 as the “3D Google earth images”. Except some measurement points in Torul, Kürtün and Şiran districts (e.g., TR3, K3, K6, K9, SR10, SR14, SR25, SR28, SR29, SR30, SR52), estimated predominant frequency values generally changes between 3.0–9.8 and the H/V peak amplitude values about between 1.0–2.0 (Tables 1, 2 and 4). This situation can be commented as a discrepancy between the near surface geology of the studied districts and the estimated soil types. However, according to the ground type classification of Kanai and Tanaka (1961), these regions mostly coincide with Z₁ subsoil type and therefore, it can be said that the amplification factor will not have an effective role in the event of a possible ground motion. In addition, K6 and K9 are the points with the highest H/V ratios of Kürtün district with their low frequency and high amplitude values. Similarly, SR28, SR29 and SR30 points of Şiran district have the largest H/V ratios of this region with their low frequency and high amplitude values. In the regions with dense settlements around the center of Kelkit, we estimated low frequency and large amplitude values whereas the frequency values are relatively large and H/V ratios are small in the areas outside the district settlement (Figures 8a, b). Since Kelkit district carries the effects of the 1992 Erzincan earthquake to a high extent, the settlement established in this district have been built as low-rise buildings. It can be said that Köse, which generally includes low frequency and large H/V ratios, has the weakest ground structure among all districts of Gümüşhane. The H/V peak amplitude values in Köse are mostly at 2.0–3.7 levels. According to results seen in Figures 6c, 7c, 8c, 9c and 10c, subsoil types of Z₁, Z₂, and Z₃ can be suggested for different districts of Gümüşhane province. Torul and Kürtün districts include the types of Z₁ whereas Kelkit, Şiran and Köse districts can be defined as Z₂ type as well standard grounds other than type Z₃ and Z₄. These results show that subsurface grounds including Z₃ type subsoil, sandy gravel, sand clay and alluvial deposits were detected in Kelkit, Şiran and...
Köse. These types of subsoils were observed in and around: i) Kelkit Aydın Doğan Vocational High School and Şehit Osman Şahin Primary School for Kelkit district, ii) Köse Public Hospital, Köse İrfan Can Vocational High School and Dormitory Directorate for Köse district, iii) Şiran Mustafa Beyaz Vocational High School and Gözde indoor sport saloon for Şiran district.

In addition to H/V ratios, Kg-values were determined to assess the soil liquefaction potential of study areas. Kg-values were computed with Equation (7) by dividing H/V ratios to predominant frequencies and the results for all districts were given in Tables 1 to 5. Akkaya [9] were computed the vulnerability indexes of buildings and identified the effect of local soil conditions and building properties on the damage levels. In this work, the limit of Kg-values was given as i) Kg≤3 low, ii) 3<Kg≤5 moderate, iii) 5<Kg≤10 high and iv) Kg≥10 very high. As shown in Tables 1 to 5, Kg-values changes between 0.12 and 22.94 for all districts. However, locally, several high and very high Kg-values were observed in and around: i) Kürtni Yankası-Uluköy Hanayani Mosque (point K6, Kg=5.81), ii) Kelkit district center (point KL26, Kg=5.16) and Şehit Osman Şahin Primary School (point KL26, Kg=5.46), iii) Şiran Atatürk Secondary School (point SR2, Kg=6.77) and Şiran Bus Station and its surrounding area (points SR34, SR35 and SR36, Kg-value between 19.75 and 22.94), iv) Köse National Education Directorate and its vicinity (points KS22 and KS23, Kg-value between 5.80 and 10.07). However, the rest Kg-values generally vary from 0.12 to 4.89 the other parts of Gümüşhane districts. Akkaya [9] stated that Kg-value can be used to define both the weak points of soil and earthquake damage before a strong/large earthquake and this parameter can supply the level of surface layer vulnerability to deformation during earthquakes. Thus, these results indicate that higher Kg-values in the given areas are composed of weak soil and the sites with Kg>5.0 are the possible regions that structural damage can occur.

Therefore, subsoil types in these areas may be considered as weaker than the other regions due to the clay and alluvial layers they contain. Hence, it can be said that there may be some problematic grounds in these regions. Considering all districts of Gümüşhane, we observed clear differences from point-to-point and it can be interpreted that this is because the surface geology has different alteration degrees in these parts. In land measurements, we observed that ground layers have different properties from region-to-region. Although the near surface geology exhibits hard ground characteristics such as volcanic rocks or granitoid, some parts of the surface geologies were observed as muddy, gravel and loose alluvial material. Therefore, it may be wrong to make a ground classification only considering the predominant frequencies. Although the resonance peak amplitude is not an exactly reliable indicator of the amplification, significantly different values can indicate different geology and ground types. Consequently, obtained results are highly related to near surface geology and suggest that predominant frequencies, H/V ratios and Kg-values vary in relation to the soil formation.

It is quite important to determine the physical, mechanical or seismic parameters of the ground accurately and reliably for the identification of the ground-structure interaction. Correct and reliable engineering services for constructions in the urbanization are of great importance in the reducing the effects of blasting in which is made rock and mine quarries, and the effects of the natural events such as earthquakes. Also, these types of engineering applications can supply significant information in order to prevent or to minimize the great damages and losses caused

### Table 1. Geographical coordinates, predominant frequencies, predominant periods, H/V ratios, Kg-values and subsoil types of 12 microtremor measurement points in Torul (TR)

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|---------------------|--------------------|-----------------------------|-----------|------------------------|----------|-------------|
| TR1                | 39.2965             | 40.5615            | 9.46                        | 1.25      | 0.11                   | 0.17     | Z₁          |
| TR2                | 39.3004             | 40.5665            | 8.95                        | 2.03      | 0.11                   | 0.46     | Z₁          |
| TR3                | 39.3001             | 40.5632            | 2.86                        | 1.22      | 0.35                   | 0.52     | Z₂          |
| TR4                | 39.2964             | 40.5595            | 4.57                        | 1.06      | 0.22                   | 0.25     | Z₁          |
| TR5                | 39.2956             | 40.5586            | 5.06                        | 1.13      | 0.19                   | 0.25     | Z₁          |
| TR6                | 39.2948             | 40.5581            | 6.41                        | 2.00      | 0.16                   | 0.62     | Z₁          |
| TR7                | 39.2915             | 40.5613            | 4.93                        | 1.51      | 0.20                   | 0.46     | Z₁          |
| TR8                | 39.2919             | 40.5630            | 6.81                        | 1.51      | 0.15                   | 0.33     | Z₁          |
| TR9                | 39.2866             | 40.5632            | 6.96                        | 1.60      | 0.14                   | 0.37     | Z₁          |
| TR10               | 39.2905             | 40.5560            | 9.84                        | 1.39      | 0.10                   | 0.20     | Z₁          |
| TR11               | 39.2914             | 40.5591            | 5.41                        | 1.51      | 0.18                   | 0.42     | Z₁          |
| TR12               | 39.2929             | 40.5553            | 5.92                        | 1.40      | 0.17                   | 0.33     | Z₁          |
Table 2. Geographical coordinates, predominant frequencies, predominant periods, H/V ratios, Kg-values and subsoil types of 9 microtremor measurement points in Kürtün (K)

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|---------------------|--------------------|---------------------------|------------|------------------------|----------|-------------|
| K1                 | 39.0853             | 40.7022            | 6.80                      | 2.18       | 0.15                   | 0.70     | Z1          |
| K2                 | 39.0864             | 40.7006            | 6.88                      | 2.46       | 0.15                   | 0.88     | Z1          |
| K3                 | 39.0872             | 40.7017            | 2.67                      | 1.77       | 0.37                   | 1.17     | Z2          |
| K4                 | 39.0877             | 40.7070            | 8.84                      | 1.13       | 0.11                   | 0.14     | Z1          |
| K5                 | 39.0859             | 40.7054            | 9.37                      | 1.07       | 0.11                   | 0.12     | Z1          |
| K6                 | 39.0853             | 40.7028            | 2.59                      | 3.88       | 0.39                   | 5.81     | Z1          |
| K7                 | 39.0864             | 40.7019            | 3.71                      | 1.90       | 0.27                   | 0.97     | Z2          |
| K8                 | 39.0872             | 40.7028            | 3.18                      | 1.83       | 0.31                   | 1.05     | Z2          |
| K9                 | 39.0897             | 40.7003            | 2.69                      | 2.99       | 0.37                   | 3.23     | Z2          |

Table 3. Geographical coordinates, predominant frequencies, predominant periods, H/V ratios, Kg-values and subsoil types of 48 microtremor measurement points in Kelkit (KL)

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|---------------------|--------------------|---------------------------|------------|------------------------|----------|-------------|
| KL1                | 39.4333             | 40.1352            | 3.90                      | 2.01       | 0.26                   | 1.04     | Z1          |
| KL2                | 39.4327             | 40.1382            | 3.24                      | 1.23       | 0.31                   | 0.47     | Z1          |
| KL3                | 39.4305             | 40.1278            | 9.54                      | 2.07       | 0.10                   | 0.45     | Z1          |
| KL4                | 39.4311             | 40.1304            | 6.84                      | 1.96       | 0.15                   | 0.56     | Z1          |
| KL5                | 39.4259             | 40.1270            | 1.75                      | 2.82       | 0.57                   | 4.54     | Z1          |
| KL6                | 39.4324             | 40.1249            | 1.45                      | 2.43       | 0.69                   | 4.07     | Z1          |
| KL7                | 39.4374             | 40.1259            | 3.60                      | 1.48       | 0.28                   | 0.61     | Z1          |
| KL8                | 39.4352             | 40.1287            | 5.11                      | 4.36       | 0.19                   | 3.72     | Z1          |
| KL9                | 39.4396             | 40.1293            | 5.28                      | 5.08       | 0.19                   | 4.89     | Z1          |
| KL10               | 39.4412             | 40.1333            | 8.87                      | 3.49       | 0.11                   | 1.37     | Z1          |
| KL11               | 39.4430             | 40.1312            | 8.58                      | 3.56       | 0.12                   | 1.47     | Z1          |
| KL12               | 39.4381             | 40.1333            | 3.16                      | 1.36       | 0.32                   | 0.59     | Z1          |
| KL13               | 39.4453             | 40.1344            | 3.17                      | 1.37       | 0.32                   | 0.59     | Z1          |
| KL14               | 39.4292             | 40.1341            | 2.70                      | 2.97       | 0.37                   | 3.27     | Z1          |
| KL15               | 39.4385             | 40.1360            | 3.18                      | 2.91       | 0.31                   | 2.66     | Z1          |
| KL16               | 39.4417             | 40.1483            | 4.05                      | 2.43       | 0.25                   | 1.46     | Z1          |
| KL17               | 39.4440             | 40.1460            | 4.41                      | 2.49       | 0.23                   | 1.41     | Z1          |
| KL18               | 39.4324             | 40.1452            | 3.38                      | 1.97       | 0.30                   | 1.15     | Z1          |
| KL19               | 39.4323             | 40.1416            | 4.28                      | 2.09       | 0.23                   | 1.02     | Z1          |
| KL20               | 39.4370             | 40.1445            | 3.34                      | 1.32       | 0.30                   | 0.52     | Z1          |
| KL21               | 39.4391             | 40.1463            | 3.36                      | 1.34       | 0.30                   | 0.53     | Z1          |
| KL22               | 39.4454             | 40.1426            | 5.27                      | 2.00       | 0.19                   | 0.75     | Z1          |
| KL23               | 39.4424             | 40.1426            | 4.97                      | 3.17       | 0.20                   | 2.02     | Z1          |
| KL24               | 39.4425             | 40.1393            | 4.80                      | 2.84       | 0.21                   | 1.68     | Z1          |
| KL25               | 39.4350             | 40.1309            | 5.16                      | 4.56       | 0.19                   | 4.03     | Z1          |
| KL26               | 39.4323             | 40.1330            | 5.20                      | 5.18       | 0.19                   | 5.16     | Z1          |
| KL27               | 39.4361             | 40.1219            | 3.11                      | 1.68       | 0.32                   | 0.91     | Z1          |
| KL28               | 39.4405             | 40.1221            | 1.27                      | 1.86       | 0.79                   | 2.72     | Z1          |

(continues)
### Table 3. Continued

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|---------------------|-------------------|---------------------------|-----------|------------------------|----------|-------------|
| KL29               | 39.4388             | 40.1201           | 7.48                      | 3.36      | 0.13                   | 1.51     | Z₁          |
| KL30               | 39.4439             | 40.1210           | 7.48                      | 3.36      | 0.13                   | 1.51     | Z₁          |
| KL31               | 39.4420             | 40.1174           | 9.06                      | 2.42      | 0.11                   | 0.65     | Z₁          |
| KL32               | 39.4463             | 40.1184           | 8.98                      | 2.40      | 0.11                   | 0.64     | Z₁          |
| KL33               | 39.4487             | 40.1111           | 2.59                      | 1.75      | 0.39                   | 1.18     | Z₁          |
| KL34               | 39.4520             | 40.1116           | 4.54                      | 1.01      | 0.22                   | 0.22     | Z₁          |
| KL35               | 39.4500             | 40.1137           | 2.60                      | 1.73      | 0.38                   | 1.15     | Z₁          |
| KL36               | 39.4476             | 40.1127           | 1.40                      | 2.52      | 0.72                   | 4.54     | Z₁          |
| KL37               | 39.4396             | 40.1146           | 8.85                      | 1.62      | 0.11                   | 0.30     | Z₁          |
| KL38               | 39.4381             | 40.1178           | 4.72                      | 1.40      | 0.21                   | 0.42     | Z₁          |
| KL39               | 39.4440             | 40.1160           | 6.06                      | 1.44      | 0.17                   | 0.34     | Z₁          |
| KL40               | 39.4449             | 40.1140           | 3.13                      | 1.01      | 0.32                   | 0.33     | Z₁          |
| KL41               | 39.4385             | 40.1492           | 1.84                      | 3.17      | 0.54                   | 5.46     | Z₁          |
| KL42               | 39.4365             | 40.1476           | 3.75                      | 2.33      | 0.27                   | 1.45     | Z₁          |
| KL43               | 39.4354             | 40.1342           | 4.42                      | 4.08      | 0.23                   | 3.77     | Z₁          |
| KL44               | 39.4358             | 40.1456           | 2.75                      | 1.75      | 0.36                   | 1.11     | Z₁          |
| KL45               | 39.4365             | 40.1429           | 3.09                      | 1.81      | 0.32                   | 1.06     | Z₁          |
| KL46               | 39.4482             | 40.1151           | 2.90                      | 1.51      | 0.34                   | 0.79     | Z₁          |
| KL47               | 39.4406             | 40.1443           | 8.20                      | 2.60      | 0.12                   | 0.82     | Z₁          |
| KL48               | 39.4441             | 40.1444           | 7.62                      | 2.46      | 0.13                   | 0.79     | Z₁          |

### Table 4. Geographical coordinates, predominant frequencies, predominant periods, H/V ratios, Kg-values and subsoil types of 60 microtremor measurement points in Şirán (SR)

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|---------------------|-------------------|---------------------------|-----------|------------------------|----------|-------------|
| SR1                | 39.1302             | 40.1936           | 5.32                      | 4.90      | 0.19                   | 4.51     | Z₁          |
| SR2                | 39.1299             | 40.1958           | 5.41                      | 6.05      | 0.18                   | 6.77     | Z₁          |
| SR3                | 39.1308             | 40.1895           | 6.93                      | 1.86      | 0.14                   | 0.50     | Z₁          |
| SR4                | 39.1187             | 40.1931           | 6.80                      | 2.72      | 0.15                   | 1.09     | Z₁          |
| SR5                | 39.1218             | 40.1936           | 6.59                      | 2.93      | 0.15                   | 1.30     | Z₁          |
| SR6                | 39.1194             | 40.1912           | 6.45                      | 2.83      | 0.16                   | 1.24     | Z₁          |
| SR7                | 39.1130             | 40.1793           | 4.71                      | 2.21      | 0.21                   | 1.04     | Z₁          |
| SR8                | 39.1156             | 40.1797           | 4.68                      | 2.09      | 0.21                   | 0.93     | Z₁          |
| SR9                | 39.1181             | 40.1777           | 4.87                      | 2.43      | 0.21                   | 1.21     | Z₁          |
| SR10               | 39.1262             | 40.1945           | 2.46                      | 1.78      | 0.41                   | 1.29     | Z₁          |
| SR11               | 39.1275             | 40.1964           | 3.14                      | 1.87      | 0.32                   | 1.11     | Z₁          |
| SR12               | 39.1257             | 40.1921           | 3.14                      | 1.86      | 0.32                   | 1.10     | Z₁          |
| SR13               | 39.1228             | 40.1926           | 3.79                      | 1.86      | 0.26                   | 0.91     | Z₁          |
| SR14               | 39.1273             | 40.1903           | 2.78                      | 2.12      | 0.36                   | 1.62     | Z₁          |
| SR15               | 39.1239             | 40.1791           | 3.10                      | 1.62      | 0.32                   | 0.85     | Z₁          |
| SR16               | 39.1251             | 40.1793           | 4.76                      | 1.85      | 0.21                   | 0.72     | Z₁          |
| SR17               | 39.1247             | 40.1805           | 4.67                      | 1.85      | 0.21                   | 0.73     | Z₁          |
| SR18               | 39.1240             | 40.1819           | 4.75                      | 2.03      | 0.21                   | 0.87     | Z₁          |

(continues)
| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|--------------------|--------------------|---------------------------|-----------|------------------------|----------|-------------|
| SR19               | 39.1208            | 40.1881            | 3.94                      | 1.91      | 0.25                   | 0.93     | Z2          |
| SR20               | 39.1179            | 40.1874            | 3.87                      | 1.96      | 0.26                   | 0.99     | Z2          |
| SR21               | 39.1185            | 40.1895            | 3.96                      | 1.96      | 0.25                   | 0.97     | Z2          |
| SR22               | 39.1191            | 40.1798            | 8.00                      | 3.09      | 0.12                   | 1.19     | Z2          |
| SR23               | 39.1219            | 40.1801            | 8.04                      | 3.05      | 0.12                   | 1.16     | Z2          |
| SR24               | 39.1207            | 40.1814            | 8.05                      | 3.11      | 0.12                   | 1.20     | Z2          |
| SR25               | 39.1157            | 40.1831            | 2.98                      | 1.60      | 0.34                   | 0.86     | Z2          |
| SR26               | 39.1151            | 40.1814            | 3.17                      | 1.45      | 0.32                   | 0.66     | Z2          |
| SR27               | 39.1168            | 40.1842            | 3.07                      | 1.53      | 0.33                   | 0.76     | Z2          |
| SR28               | 39.1340            | 40.1949            | 2.53                      | 2.43      | 0.39                   | 2.33     | Z2          |
| SR29               | 39.1327            | 40.1931            | 2.14                      | 2.65      | 0.47                   | 3.28     | Z2          |
| SR30               | 39.1304            | 40.1917            | 2.40                      | 2.38      | 0.42                   | 2.36     | Z2          |
| SR31               | 39.1302            | 40.1980            | 5.16                      | 2.24      | 0.19                   | 0.97     | Z2          |
| SR32               | 39.1332            | 40.1964            | 5.33                      | 2.05      | 0.19                   | 0.79     | Z2          |
| SR33               | 39.1256            | 40.1971            | 5.06                      | 2.52      | 0.19                   | 1.26     | Z2          |
| SR34               | 39.1248            | 40.1850            | 3.89                      | 9.24      | 0.26                   | 21.95    | Z2          |
| SR35               | 39.1231            | 40.1840            | 4.00                      | 9.58      | 0.25                   | 22.94    | Z2          |
| SR36               | 39.1220            | 40.1825            | 3.93                      | 8.81      | 0.25                   | 19.75    | Z2          |
| SR37               | 39.1250            | 40.1883            | 7.40                      | 4.28      | 0.14                   | 2.48     | Z2          |
| SR38               | 39.1234            | 40.1868            | 7.20                      | 4.35      | 0.14                   | 2.63     | Z2          |
| SR39               | 39.1279            | 40.1886            | 7.17                      | 4.46      | 0.14                   | 2.77     | Z2          |
| SR40               | 39.1378            | 40.1979            | 8.06                      | 2.18      | 0.12                   | 0.59     | Z2          |
| SR41               | 39.1352            | 40.1975            | 5.85                      | 2.48      | 0.17                   | 1.05     | Z2          |
| SR42               | 39.1365            | 40.1950            | 8.34                      | 1.97      | 0.12                   | 0.47     | Z2          |
| SR43               | 39.1180            | 40.1831            | 7.04                      | 4.87      | 0.14                   | 3.37     | Z2          |
| SR44               | 39.1185            | 40.1818            | 7.22                      | 4.34      | 0.14                   | 2.61     | Z2          |
| SR45               | 39.1207            | 40.1833            | 6.98                      | 4.48      | 0.14                   | 2.88     | Z2          |
| SR46               | 39.1193            | 40.1843            | 7.13                      | 4.40      | 0.14                   | 2.72     | Z2          |
| SR47               | 39.1175            | 40.1976            | 6.31                      | 3.50      | 0.16                   | 1.94     | Z2          |
| SR48               | 39.1183            | 40.1958            | 6.21                      | 4.04      | 0.16                   | 2.63     | Z2          |
| SR49               | 39.1198            | 40.1982            | 6.33                      | 3.22      | 0.16                   | 1.64     | Z2          |
| SR50               | 39.1217            | 40.1908            | 4.64                      | 1.65      | 0.22                   | 0.59     | Z2          |
| SR51               | 39.1229            | 40.1892            | 4.52                      | 1.67      | 0.22                   | 0.62     | Z2          |
| SR52               | 39.1244            | 40.1902            | 2.96                      | 1.71      | 0.34                   | 0.99     | Z2          |
| SR53               | 39.1212            | 40.1953            | 9.43                      | 2.43      | 0.11                   | 0.63     | Z2          |
| SR54               | 39.1222            | 40.1980            | 6.68                      | 1.41      | 0.15                   | 0.30     | Z2          |
| SR55               | 39.1243            | 40.1961            | 6.42                      | 1.41      | 0.16                   | 0.31     | Z2          |
| SR56               | 39.1200            | 40.1967            | 6.79                      | 1.41      | 0.15                   | 0.29     | Z2          |
| SR57               | 39.1164            | 40.1895            | 4.04                      | 1.49      | 0.25                   | 0.55     | Z2          |
| SR58               | 39.1180            | 40.1858            | 8.21                      | 2.27      | 0.12                   | 0.63     | Z2          |
| SR59               | 39.1219            | 40.1855            | 8.10                      | 2.43      | 0.12                   | 0.73     | Z2          |
| SR60               | 39.1203            | 40.1870            | 8.26                      | 2.14      | 0.12                   | 0.55     | Z2          |
Table 5. Geographical coordinates, predominant frequencies, predominant periods, H/V ratios, $K_g$-values and subsoil types of 51 microtremor measurement points in Köse (KS)

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | $K_g$-value | Ground Type |
|--------------------|---------------------|--------------------|---------------------------|-----------|------------------------|-------------|-------------|
| KS1                | 39.6524             | 40.2126            | 2.80                      | 2.02      | 0.36                   | 1.46        | Z$_2$       |
| KS2                | 39.6576             | 40.2047            | 4.33                      | 2.39      | 0.23                   | 1.32        | Z$_2$       |
| KS3                | 39.6617             | 40.1981            | 3.89                      | 1.42      | 0.26                   | 0.52        | Z$_2$       |
| KS4                | 39.6620             | 40.1965            | 3.74                      | 1.21      | 0.27                   | 0.39        | Z$_2$       |
| KS5                | 39.6581             | 40.2075            | 1.71                      | 2.20      | 0.59                   | 2.83        | Z$_2$       |
| KS6                | 39.6548             | 40.2109            | 7.96                      | 1.46      | 0.13                   | 0.27        | Z$_2$       |
| KS7                | 39.6571             | 40.2115            | 4.79                      | 1.25      | 0.21                   | 0.33        | Z$_2$       |
| KS8                | 39.6554             | 40.2120            | 7.99                      | 1.50      | 0.13                   | 0.28        | Z$_2$       |
| KS9                | 39.6538             | 40.2136            | 4.44                      | 1.69      | 0.23                   | 0.64        | Z$_2$       |
| KS10               | 39.6565             | 40.2134            | 4.44                      | 1.41      | 0.23                   | 0.45        | Z$_2$       |
| KS11               | 39.6588             | 40.2113            | 5.44                      | 1.67      | 0.18                   | 0.51        | Z$_2$       |
| KS12               | 39.6589             | 40.2013            | 2.91                      | 1.62      | 0.34                   | 0.90        | Z$_2$       |
| KS13               | 39.6601             | 40.2022            | 3.81                      | 1.85      | 0.26                   | 0.90        | Z$_2$       |
| KS14               | 39.6606             | 40.2002            | 4.14                      | 1.61      | 0.24                   | 0.63        | Z$_2$       |
| KS15               | 39.6584             | 40.2146            | 6.34                      | 2.18      | 0.16                   | 0.75        | Z$_2$       |
| KS16               | 39.6594             | 40.2128            | 6.09                      | 2.67      | 0.16                   | 1.17        | Z$_2$       |
| KS17               | 39.6607             | 40.1933            | 3.96                      | 2.03      | 0.25                   | 1.04        | Z$_2$       |
| KS18               | 39.6606             | 40.1952            | 3.47                      | 2.16      | 0.29                   | 1.34        | Z$_2$       |
| KS19               | 39.6596             | 40.1979            | 2.27                      | 2.12      | 0.44                   | 1.98        | Z$_2$       |
| KS20               | 39.6554             | 40.2063            | 4.87                      | 1.09      | 0.21                   | 0.24        | Z$_2$       |
| KS21               | 39.6573             | 40.2025            | 4.83                      | 1.04      | 0.21                   | 0.22        | Z$_2$       |
| KS22               | 39.6528             | 40.2114            | 1.36                      | 3.70      | 0.73                   | 10.07       | Z$_2$       |
| KS23               | 39.6565             | 40.2070            | 1.46                      | 2.91      | 0.68                   | 5.80        | Z$_2$       |
| KS24               | 39.6541             | 40.2091            | 6.01                      | 2.75      | 0.17                   | 1.26        | Z$_2$       |
| KS25               | 39.6538             | 40.2078            | 6.16                      | 2.54      | 0.16                   | 1.05        | Z$_2$       |
| KS26               | 39.6569             | 40.2056            | 6.09                      | 4.72      | 0.16                   | 3.66        | Z$_2$       |
| KS27               | 39.6578             | 40.2038            | 2.71                      | 2.72      | 0.37                   | 2.73        | Z$_2$       |
| KS28               | 39.6529             | 40.2065            | 2.70                      | 2.67      | 0.37                   | 2.64        | Z$_2$       |
| KS29               | 39.6553             | 40.2052            | 3.23                      | 2.91      | 0.31                   | 2.62        | Z$_2$       |
| KS30               | 39.6520             | 40.2088            | 3.52                      | 2.73      | 0.28                   | 2.12        | Z$_2$       |
| KS31               | 39.6563             | 40.2038            | 3.15                      | 2.61      | 0.32                   | 2.16        | Z$_2$       |
| KS32               | 39.6557             | 40.2079            | 5.38                      | 2.67      | 0.19                   | 1.32        | Z$_2$       |
| KS33               | 39.6568             | 40.2069            | 5.46                      | 2.39      | 0.18                   | 1.05        | Z$_2$       |
| KS34               | 39.6472             | 40.2130            | 3.32                      | 2.55      | 0.30                   | 1.96        | Z$_2$       |
| KS35               | 39.6485             | 40.2146            | 4.00                      | 2.84      | 0.25                   | 2.02        | Z$_2$       |
| KS36               | 39.6490             | 40.2125            | 4.14                      | 2.38      | 0.24                   | 1.37        | Z$_2$       |
| KS37               | 39.6508             | 40.2083            | 2.66                      | 2.30      | 0.38                   | 1.99        | Z$_2$       |
| KS38               | 39.6495             | 40.2099            | 2.29                      | 2.39      | 0.44                   | 2.50        | Z$_2$       |
| KS39               | 39.6483             | 40.2116            | 2.66                      | 2.34      | 0.38                   | 2.06        | Z$_2$       |
| KS40               | 39.6543             | 40.2150            | 4.33                      | 2.18      | 0.23                   | 1.10        | Z$_2$       |
| KS41               | 39.6497             | 40.2166            | 2.79                      | 3.45      | 0.36                   | 4.27        | Z$_2$       |
| KS42               | 39.6517             | 40.2151            | 3.07                      | 3.14      | 0.33                   | 3.21        | Z$_2$       |

(continues)
Table 5. Continued

| Measurement Points | Longitude (Degrees) | Latitude (Degrees) | Predominant Frequency (Hz) | H/V Ratio | Predominant Period (s) | Kg-value | Ground Type |
|--------------------|---------------------|--------------------|---------------------------|-----------|------------------------|-----------|-------------|
| KS43               | 39.6502             | 40.2135            | 7.71                      | 2.31      | 0.13                   | 0.69      | Z₁          |
| KS44               | 39.6508             | 40.2122            | 7.63                      | 2.11      | 0.13                   | 0.58      | Z₁          |
| KS45               | 39.6463             | 40.2103            | 3.89                      | 1.15      | 0.26                   | 0.34      | Z₂          |
| KS46               | 39.6490             | 40.2074            | 5.57                      | 1.11      | 0.18                   | 0.22      | Z₁          |
| KS47               | 39.6531             | 40.2102            | 3.66                      | 2.13      | 0.27                   | 1.24      | Z₂          |
| KS48               | 39.6516             | 40.2103            | 3.77                      | 2.08      | 0.27                   | 1.15      | Z₂          |
| KS49               | 39.6502             | 40.2114            | 3.83                      | 2.21      | 0.26                   | 1.28      | Z₂          |
| KS50               | 39.6592             | 40.2054            | 1.93                      | 2.22      | 0.52                   | 2.55      | Z₃          |
| KS51               | 39.6597             | 40.2035            | 2.05                      | 1.66      | 0.49                   | 1.34      | Z₃          |

Table 6. Ground types classification of Kanai and Tanaka [11]

| Type of subsoil | Subsurface ground properties |
|-----------------|------------------------------|
| Z₁              | Stiff rock composed of gravel, sand and other soils mainly consisting of tertiary or older layers |
| Z₂              | Sandy gravel, stiff sandy clay, loam or sandy alluvial deposits whose depths are 5m or greater |
| Z₃              | Standard grounds other than type Z₁, Z₂ or Z₄ (alluvial deposits whose depths are 5m or greater) |
| Z₄              | Soft alluvium-delta lands and pit whose depth is 30m or greater. Reclaimed land from swamps or muddy shoal where the ground depth is 2m or greater and less than 20 years have passed since the reclamation by explosions in the residential area on the weak ground. Therefore, the knowledge of predominant frequency of the ground and structure will allow to avoid the possible resonance and thus, the changing the frequency of ground and/or structure will make contribution to the reduction possible damages. In recent years, microtremor technique has been used to describe the local ground conditions, especially in engineering seismology studies. Also, this technique has a significant application area and is of great importance among the geophysical techniques due to its simplicity, applicable, accuracy and reliability. Thus, the availability of microtremor measurements has increased and microtremor survey method has started to be applied in order to determine different site characteristics such as spectral amplification and predominant frequency (or period) of the grounds, and to demonstrate the local ground structure interaction. Therefore, this study can be a guide and source for the future related engineering fields in different parts of Gümüşhane since it includes useful information related to the seismicity and local subsurface structure. Estimated parameters such as predominant frequency and period, H/V ratio, Kg-value are quite important for the microzonation studies. These parameters can also be used in the selection of earthquake recording stations. Since a microzonation study was not previously performed for Gümüşhane province which has few earthquake activity, sufficient amount of single station microtremor measurements were taken in the present study. As a remarkable fact, obtained single station microtremor recordings can also be considered as the preliminary preparation for the subsequent geophysical studies in Torul, Kürtün, Köse, Şiran, Kelkit, and it can be said that microtremor technique must be absolutely and reliably taken into account in the determining the reliable ground structure interaction since the estimations of ground classifications in all study regions were verified with actual near surface deposits.

CONCLUSIONS

In recent years, the microtremor survey method has gained popularity in seismic microzonation studies and in the estimation of ground types. The main purpose of this study is to detect the site response characteristics for Torul, Kürtün, Kelkit, Şiran and Köse districts of Gümüşhane province, Turkey. For this purpose, we used the ratio of the horizontal to vertical components of Fourier amplitude spectra, designated as H/V spectral ratio model of Nakamura technique based on the single station microtremor data analysis. In this context, predominant frequency, H/V ratio and Kg-value were estimated, and subsurface ground types were made according to the predominant periods for a total of 180 measurement points including all districts.

Predominant frequency changes between 2.86 and 9.84 Hz, H/V ratio between 1.06 and 2.03 for Torul district. In addition, predominant frequency varies from 2.59 to 9.37 Hz, H/V ratio from 1.07 to 3.89 for Kürtün district; predominant frequency from 1.27 to 9.54 Hz, H/V ratio from 1.01 to 5.12 for Kelkit district; predominant frequency from...
2.14 to 9.43 Hz, H/V ratio 1.41 to 9.58 for Şiran district; predominant frequency from 1.36 to 7.99 Hz, H/V ratio 1.04 to 4.72 for Köse district. According to these values, we can suggest three main ground types such as Z₁ including stiff rock composed of gravel, sand and other soils mainly consisting of tertiary or older layers, Z₂ including sandy gravel, stiff sandy clay, loam or sandy alluvial deposits whose depths are 5m or greater, and Z₃ including standard grounds other than type Z₁, Z₂ or Z₃ (alluvial deposits whose depths are 5m or greater). According to these results, subsurface grounds including Z₃ type subsoil were detected in and around Kelkit Aydın Doğan Vocational High School and Şehit Osman Şahin Primacy School for Kelkit district, Köse Public Hospital, Köse İrfan Can Vocational High School and Dormitory Directorate for Köse district, Şiran Mustafa Beyaz Vocational High School and Gözde indoor sport saloon for Şiran district. Also, some high and very high Kg-values were detected in and around Kürtün Yakar-Uluköy Hanyani Mosque, Kelkit district center, Kelkit Şehit Osman Şahin Primary School, Şiran Atatürk Secondary School, Şiran Bus Station and its surrounding area, Köse National Education Directorate and its vicinity. In terms of the risk assessment, these results show that the grounds in these mentioned settlements are not suitable for the next constructions. Also, obtained findings may be significant for taking necessary precautions in constructing engineering projects in these areas. These conclusions show that predominant frequencies, H/V ratios and Kg-values highly correspond to these subsurface ground types, and there is a good correlation among the H/V ratio, predominant frequency and actual near surface deposits. These findings can serve as the primary data sources for the other geophysical, geological and geotechnical studies such as seismic hazard microzonation and seismic site response works for Torul, Kürtün, Kelkit, Şiran and Köse districts of Gümüşhane province. As an important result, accurate and reliable surveys including the microtremor measurements could be one of the useful methods for seismic microzonation and disaster mitigation, even when detailed seismic hazard data or soil profile data is not available.
Figure 7. “Google Earth” images of Kürtün district for (a) Predominant frequency, (b) H/V spectral ratio and (c) Subsurface ground profiles from predominant period.

Figure 8. “Google Earth” images of Kelkit district for (a) Predominant frequency, (b) H/V spectral ratio and (c) Subsurface ground profiles from predominant period. The areas with $Z_i$ ground type were mentioned in the text.

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AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw
data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The author declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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