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Investigation of Ambient Seismic Noise in Different Region of Georgia

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ABSTRACT

Georgia, like the whole South Caucasus, is a tectonically and structurally complex region. It is one of the active segments of the Alpine-Himalayan belt, therefore it is important to assess the seismic hazard for Georgia. At the regional scale, this assessment is evaluated by applying probabilistic seismic hazard analysis that identifies the annual probability of exceedance of various ground motion levels defined in terms of selected ground motion intensity measures, such as PGA or spectral accelerations (SA) corresponding to various return periods related to possible future earthquake scenarios for a site represented by soil classes A according to EC8, Euro-code 8-EN 1998-1 (1998). At the local scale, seismic hazard assessment is made by analyzing the geological, geomorphological, geotechnical and geophysical characteristics of the site, as it is well established that the incoming seismic motion can change in amplitude, frequency, and duration due the site-specific local characteristics. That is the subject of micro-zonation investigation. Site – specific local characteristics are presented by the following parameters: Dominant frequency, Vs,30 (average shear-wave velocity to a depth of 30 meters) and amplification factor. In this work, we presented results of geophysical survey assessing local site conditions by dominant frequency that allows identification of similar seismic response areas. For this purpose, seismic noise records have been used first time in Georgia.

Keywords: *Ambient Vibration, Single Station, Ground Motion, Amplification, H/V Method.*

Introduction

The various impacts of earthquakes on the Earth's surface have brought attention to studying how the ground responds to earthquakes with different magnitudes [1-10]. The amplification of seismic ground motion, caused by site effects, plays a crucial role in the observed destruction during earthquakes. Depending on the site conditions, the earthquake damage can vary across different regions. During the earthquake, soft sediments exhibit noticeable ground motion amplification compared to consolidated rocks. Consequently, buildings situated on these sediments are more prone to damage or complete collapse. This amplification in ground motion is caused by resonance frequency of corresponding sites. Traditional approaches to quantify resonant frequencies have relied on earthquake ground motion recordings of investigation sites. However, the poor data of strong motion in Georgia does not allow us to follow this approach. Availability of seismic noise records has opened up new possibilities for studying ground response characteristics, particularly to estimate dominant frequency of the site [1-10].

The Horizontal to Vertical Spectral Ratio (HVSR or H/V) technique is a widespread approach for site characterization [1-10]. It can be applied by ground motion records caused by earthquakes and ambient noise records. An important advantage of HVSR technique is that it eliminates the influence of the source and provides information on the wave propagation in the environment.

By utilizing seismic noise data, the HVSR technique enables the extraction information about the resonant frequencies of the underlying soil layers. The peaks observed in the HVSR curves correspond to the resonance frequencies, offering insights into the site's dynamic properties [7,9,10]. Knowledge of resonance frequencies of the ground is important when designing structures so that their natural frequency does not coincide with the resonant frequency of the ground.

Determination of resonant frequencies using seismic noise records

In this work, we concentrated only on the assessment of fundamental frequency. To demonstrate the effectiveness of the proposed methodology, a case study is conducted in a different region of Georgia. Seismic noise data collected from multiple stations are processed, and the HVSR curves are computed. The peaks observed in the HVSR curves are analyzed to determine the resonant frequencies of the underlying soil layers.

We used the TROMINO 3G seismograph (www.tromino.eu) with an output sampling rate 128 Hz, which are all-in-one instruments expressly designed for tremor measurements and maximum portability (approximately $1dm^3$volume and 1 kg weight). During installation, small holes were dug to accommodate the sensors on the ground whenever possible, usual care was taken in deploying the sensors and ensuring adequate coupling with the soil. Care was taken also at ensuring to avoid placement of sensors directly over utilities or disturbances sources.

Seismic noise was sampled approximately for 30 – 45 minutes at each site and HVSR curves were calculated by averaging the H/V obtained by dividing the signal into overlapping windows of 20s. Each window was detrended, tapered, padded, FFT and smoothed with triangular windows with a width equal to 10% of the central frequency before the Fourier spectra were ratioed, and the Euclidean average was used to combine EW and NS components in the single horizontal (H) spectrum. We consider records only in the range 0.1-20 Hz which is more interesting from an Engineering point of view.

Geophysical measurements were carried out in the area allocated for the construction of hydroelectric power stations in the mountainous regions of West Georgia, at the construction site of multi-apartment residential buildings in the city of Tbilisi, at the construction site of a hotel complex in Batumi, and in the area of the tailing dam in Kazreti.

The recorded time series data is converted to the frequency domain using FFT for all three components. The resonance manifests itself as a local minimum in the vertical velocity component in the frequency domain, such that when a ratio is taken between the averaged horizontal and vertical components of ground velocity, a peak occurs at a particular frequency as shown in Fig. 1 [1, 2]. This resonance frequency is related to the shear wave velocity and thickness of the first layer by the following equation :

$$f_0 = \frac{V_s}{4h} \quad \text{equation (1)}$$

where f_0 is a peak resonant frequency (Hz), $V_s$is a shear wave velocity (m/s), h is a thickness of the layer.

$$h = \frac{V_s}{4f_0} \quad \text{equation (2)}$$

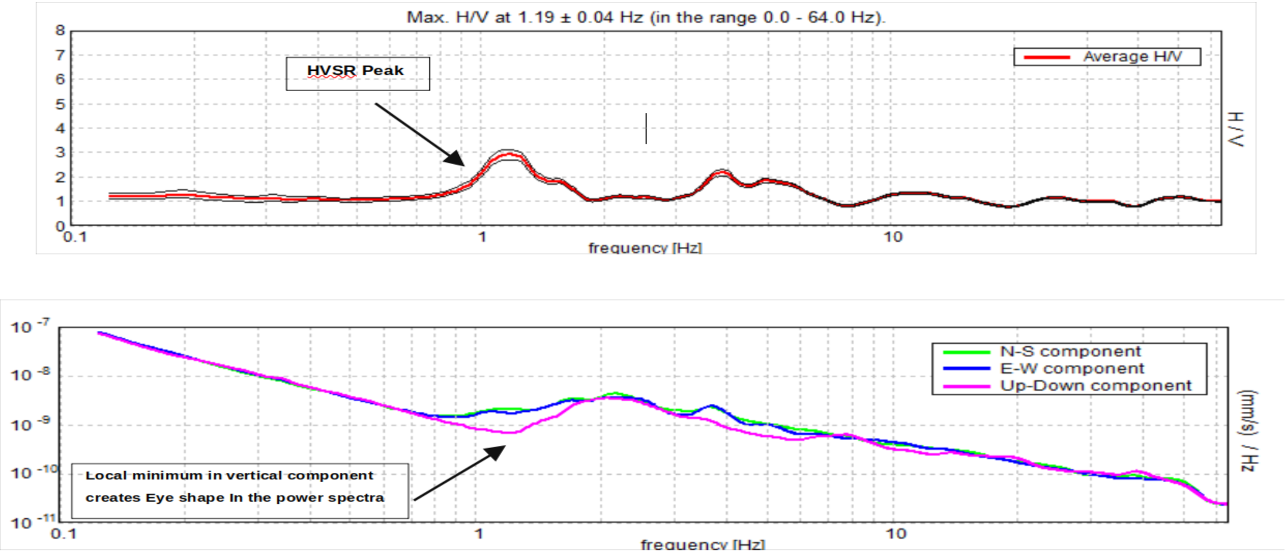


Fig. 1. Record from a Tromino 3G seismometer. HVSR curve in the top panel, and the Fourier spectrum of the three axial components in the bottom panel. Resonance frequency is observed at a peak of 1.19 Hz in the HVSR plot.

When analyzing the spectrum of individual components of Tromino's record, the presence of a one-dimensional (1D) environment can be determined if the horizontal components coincide and a local minimum is observed on the vertical component. In this case, Equations (1) and (2) can be applied as they are valid for a 1D scenario [7] (Fig. 1).

However, if the spectrum of individual components of the Tromino record does not match, indicating a two-dimentional (2D) environment, the relationship between the depth of the sedimentary layer (thickness of the sedimentary layer), resonant frequency and shear wave velocity presented by equation (1) and (2) cannot be used. In such cases, alternative approaches are necessary to calculate the layer thickness and shear wave velocity [7,10].

Analysis of Ambient Seismic Noise Data

The analysis of the seismic noise measurements revealed that the construction area of Bakhvi 1 HPP headwork is mainly composed of foundations, where the seismic noise records correspond to the rock as HV curve has no peak. This allows us to assess the seismic hazard for the rock in the area. Consequently, the amplification factor in this case is expected to be 1. As for the area of Bakhvi 1 HPP power station, peak was observed here at frequencies in the range of 15-19Hz indicating that the bedrock is quite close to the surface. Fig. 2 presents the distribution of dominant frequency at Bakhvi 1 HPP Power Station. Fig. 3a) b shows examples of HV curves of Bakhvi 1 HPP power station and Headwork.

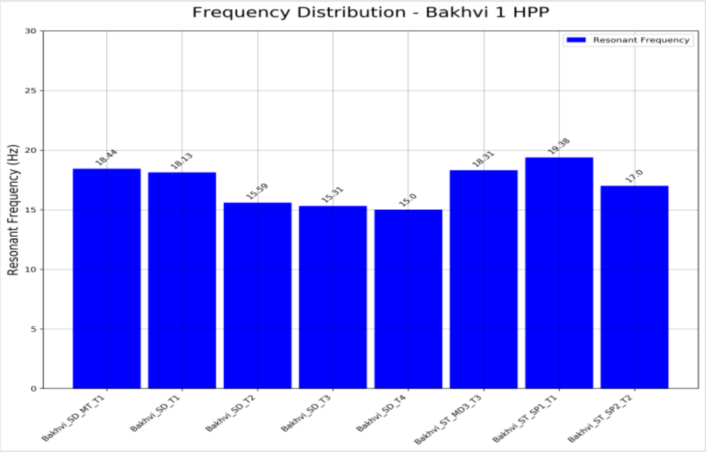
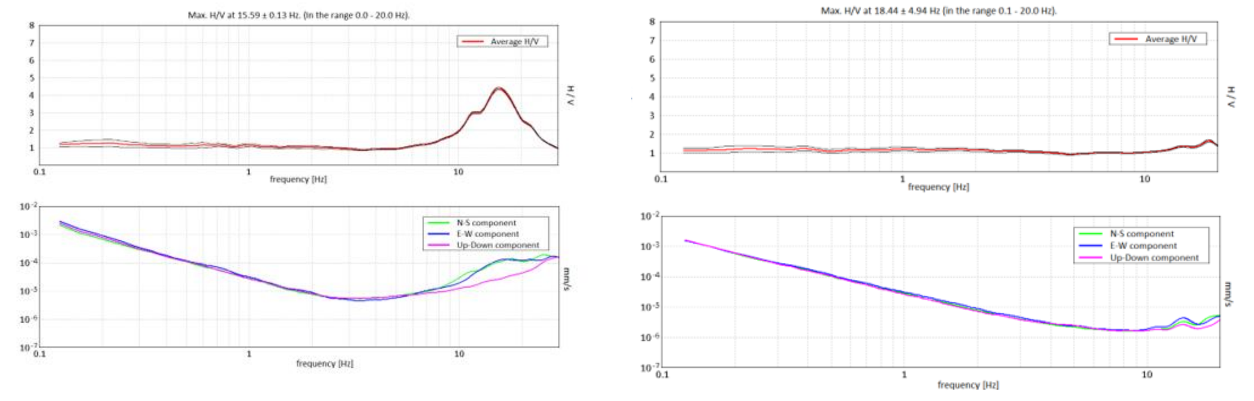


Fig. 2. Frequency Distribution for Bakhvi 1 HPP Power Station.

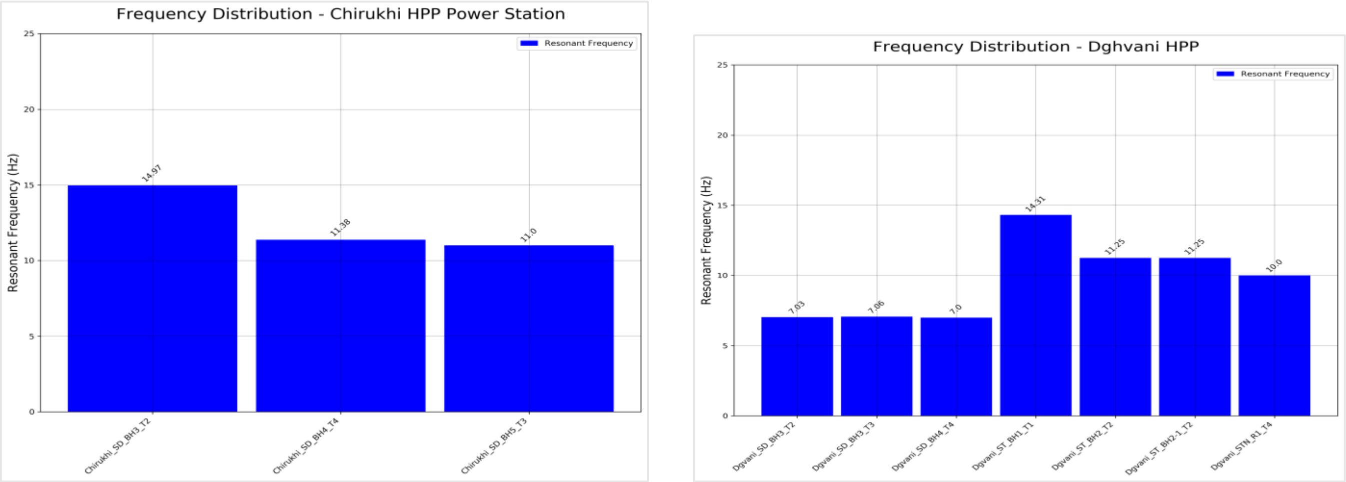


a) b)

Fig. 3. HVSR curves and Fourier spectrum of N-S, E-W and Up-Down components of the ground velocity (in range 0.1-20Hz) of Bakhvi 1HPP a) HPP power station b) HPP Headwork.

Ambient noise measurements were also conducted at the construction sites of Chirukhi HPP and Dghvani HPP. Ambient vibration measurements were taken at a total of 14 points, with 3 points located at Chirukhi HPP power station, 4 points located at Chirukhi HPP headwork, and the remaining 7 points at Dghvani HPP, four of them at headwork and three at power station.

The analysis of the seismic noise measurements revealed that the area of Cirukhi HPP headwork represented by the rock (Fig. 5) and the area of Cirukhi HPP power station characterized by resonance frequencies in the range of 11.0 -15 Hz (Fig. 4 a). Seismic noise records at Dghvani HPP exhibit a mixture of resonance frequencies. The power station of Dghvani HPP shows a similar value of a resonance frequency at 7-7.06 Hz. The headwork of Dghvani HPP, however, is characterized by high resonant frequencies ranging from 10 – 14.31 Hz (Fig. 4b).



a) b)

Fig. 4. Frequency distribution a) For Chirukhi HPP power station; b) For Dgvani HPP headwork and power station

Fig. 5 a) b)c)d) presents one of the examples of HV curves of seismic noise measurement at Chirukhi HPP and Dgvani HPP sites.

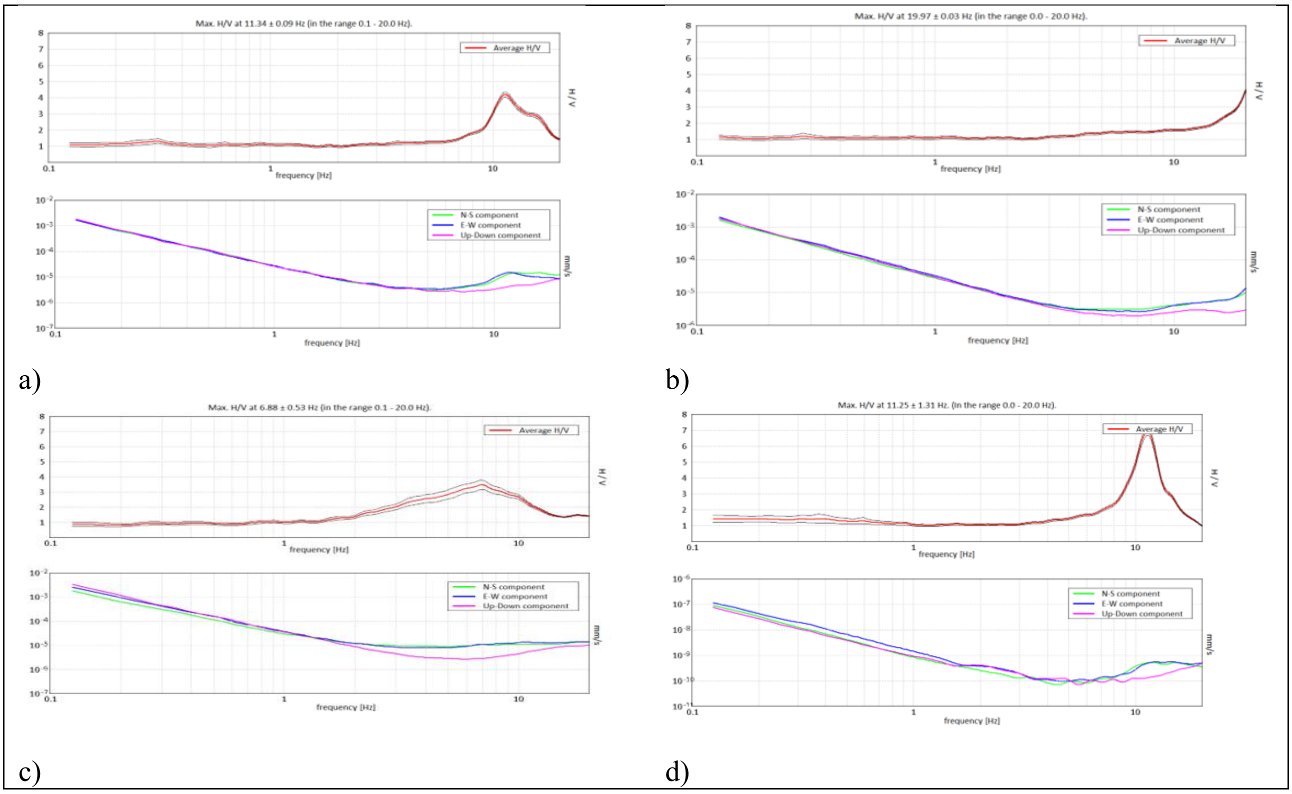


Fig. 5. HVSR curves and Fourier spectrum Frequency-Amplitude curves of N-S, E-W and Up-Down components of the ground velocity a) For Chirukhi HPP power station b) For Chirukhi HPP headwork c) For Dgvani HPP power station d) For Dgvani HPP headwork

Seismic nose measurement records were investigated at the top and bottom of Kazreti Tailing Dam. The analysis of the seismic noise records at the bottom of Kazreti Tailing Dam showed that no peak were observed on the HV curve. Amplitudes across the entire frequency spectrum are less than 2, which means the foundation is rock (Fig. 7b). On the other side peak on the HV curve was observed at a lower frequency at the top of Kazreti Tailing Dam (Fig. 7a) which justifies the homogeneity of the material used to raise the dam. The low value of resonance frequency corresponds to the Height of the tailing Dam which is about 170 m.

Fig. 6 shows the distribution of dominant frequency at the top of Kazreti Tailing Dam. Fig. 7a) b) presents one of the examples of HV curves of seismic noise measurements at the top and bottom of Kazreti Tailing Dam correspondingly.

a)

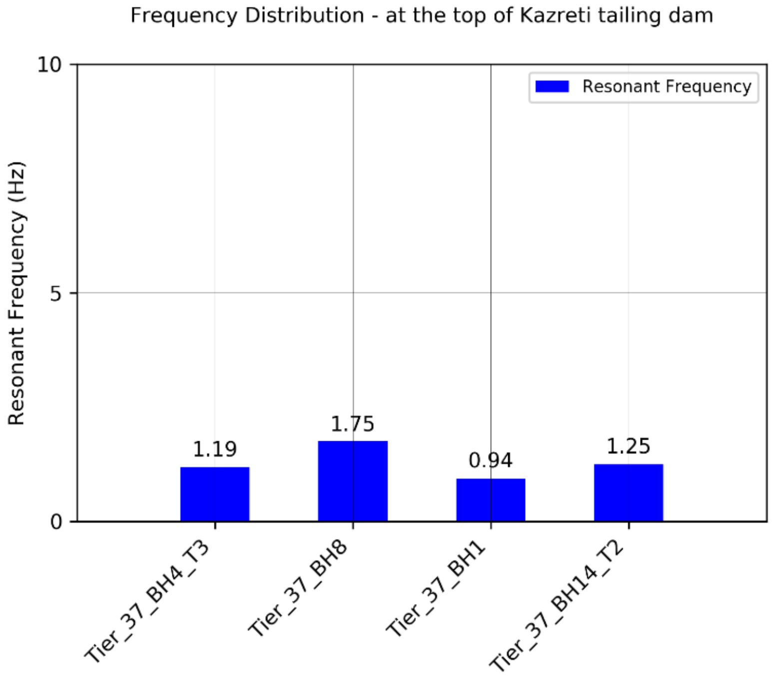
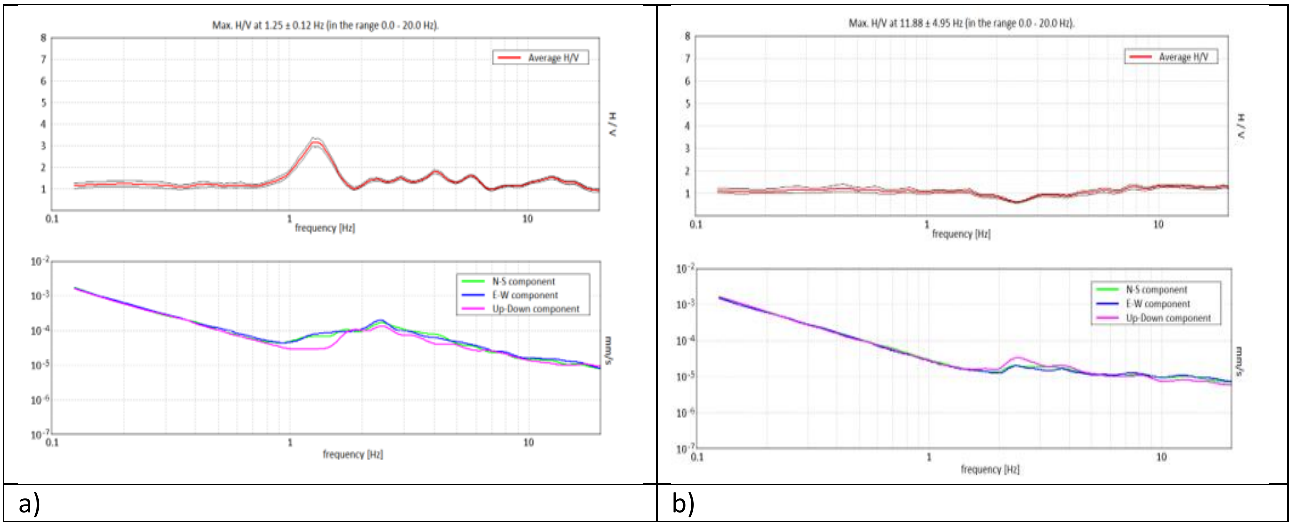


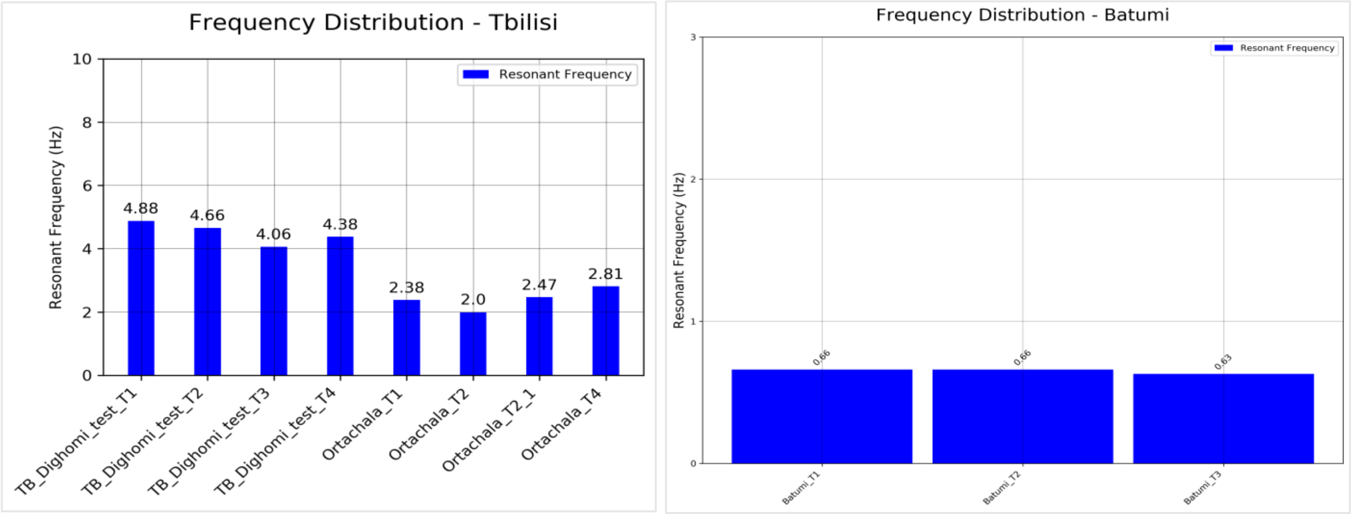
Fig. 6. Frequency Distribution at the top of Kazreti Tailing Dam



a) b)

Fig. 7. a) b) HVSR curves and Fourier spectrum of N-S, E-W and Up-Down components of the ground velocity at the top and bottom of the Kazreti Tailing Dam correspondingly.

Below are presented the same analyses of seismic records for multi-apartment residential houses in Tbilisi and a hotel complex in Batumi. Fig. 8 a) b) presents the dominant frequency distribution for these sites and Fig. 9 a) b) HVSR curves and Fourier spectrum for investigated sites in Tbilisi and Batumi correspondingly. (Figure 10,11).



a) b)

Fig. 8. Frequency Distribution for a) Tbilisi b) Batumi

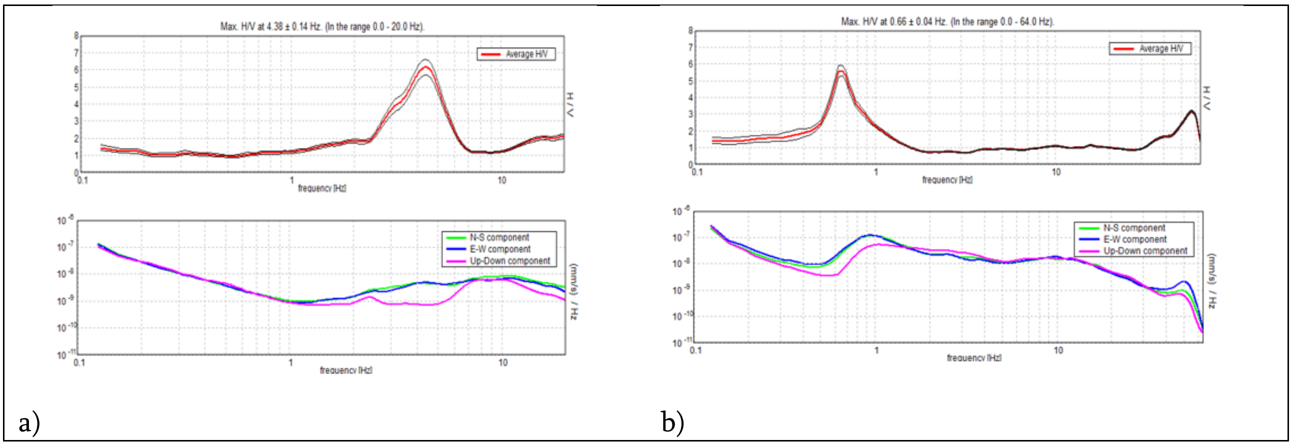


Fig. 9 HVSR curves and Fourier spectrum of N-S, E-W and Up-Down components of the ground velocity (in range 0.1-20Hz) a) Tbilisi b) Batumi.

The conducted studies show that the bedrock of mountainous regions of Georgia comes to the surface because no peak is observed. However, medium frequencies were also observed in the terraced parts of these regions.

In contrast, the Batumi territory exhibited low frequencies (0.6 Hz), which suggests the presence of bedrock at considerable depths, far from the surface. Similarly, the records at the top of Kazreti Tailing Dam displayed low frequencies, indicating the uniformity of the underlying materials used to raise the dam. Seismic surveys conducted at the bottom of the Dam revealed the presence of bedrock. As a result, the mountainous regions of Georgia are characterized by high resonance frequencies, while the plains exhibit low resonance frequencies. The obtained results give us the idea to characterize areas with similar seismic response behavior in the future by collecting information from such cheap measurements as seismic noise. These findings are crucial for assessing local seismic hazards and calculating the seismic hazard of critical infrastructure in relation to ground response.

Conclusion

Estimation dominant frequency by H/V technique is a widespread method today, though this method is being used for the first time in Georgia. Up to now, equation (1) was used to estimate the dominant frequencies of the ground theoretically when the layer's thickness and matching velocity were known from other seismic data. This approach is not justified in all cases, in particular when the environment is not one-dimensional. Also, when we have several layers, the dominant frequency of the second layer is determined by another approach. [10]

The study of resonance frequencies with seismic noise in different regions of Georgia showed us different values. In particular, the mountainous regions of Georgia are characterized by high resonance frequencies or HV curves without peak, while the plains exhibit low resonance frequencies.

Dominant frequencies are not considered in ground motion prediction equations (GMPE). Site conditions are typically represented by average shear wave velocity (Vs30), which is not enough to study local seismicity. We think that it is important to include the dominant frequency as a separate parameter in GMPE models.

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References:

[1] Nakamura Y. A method for dynamic characteristics estimation of subsurface using micro tremor on the ground surface. Quarterly Report of Railway Technical Research Institute (RTRI), Vol. 30(1), 1989, pp. 25-30.

[2] Nakamura Y. Clear identification of fundamental idea of Nakamura's technique and its applications. 12WCEE, 2656, 2000.

[3] Gutenberg B. Die seismische Bodenunruhe. Ph.D. thesis, University of Gottigen, Germany, In German, 1911.

[4] Gutenberg B. Microseisms in North America, Bull. Seismol. Soc. Am., 21, 1931, pp.1-24.

[5] Gutenberg B. Microseisms. Advances in Geophysics, 5, 1958, pp. 53-92.

[6] Nakamura Y. On The H/V Spectrum, 14WCEE, 2008.

[7] Castellaro C., Mulargia F. The Effect of Velocity Inversions on H/V. Pure and Applied Geophysics, vol. 166, April 2009, pp. 567-592.

[8] Xu R., Wang L. The horizontal-to-vertical spectral ratio and its applications. EURASIP Journal on Advances in Signal Processing, 75, 2021.

[9] Harutoonian P., Leo Ch., J., Liyanapathirana S., Womg H. Site Characterization by The HVSR Technique**.** Australian Geomechanics Journal, 47(3), 2012, pp.103-112**.**

[10] Castelarro C. The complementarity of H/V and dispersion curve. Geophysics, Vol. 81(6), 2016, pp. 1-23. https://doi.org/10.1190/geo2015-0399.1.

გრუნტის თვისებების შესწავლა კრიტიკული ინფრასტრუქტურისთვის

თ. შუბლაძე, ნ. წერეთელი

რეზიუმე

საქართველო ისევე როგორც მთლიანად სამხრეთ კავკასია, ერთ-ერთი სეისმურად აქტიური რეგიონია ალპურ-ჰიმალაის სეისმურ სარტყელში. ამიტომ სეისმური საშიშროების შეფასება მნიშვნელოვანია საქართველოსთვის. ნაციონალურ დონეზე სეისმური საშიშროების შეფასება ხდება ალბათური სეისმური საშიშროების მეთოდით, რომელიც განსაზღვრავს გრუნტის სხვადასხვა დონის რხევების წლიური გადაჭარბების ალბათობას. გრუნტის რხევები გამოსახულია რხევის პიკური და სპექტრალური აჩქარებებით. ხოლო შეფასება ხდება გრუნტის A კლასისთვის ევროკოდი 8-EN 1998-1 (1998) მიხედვით.

ლოკალური მასშტაბით, სეისმური საშიშროების დაზუსტება ხდება უბნის გეოლოგიური, გეომორფოლოგიური, გეოტექნიკური და გეოფიზიკური მახასიათებლების მიხედვით, ვინაიდან

ცნობილია, რომ შემომავალი სეისმური რხევები შეიძლება შეიცვალოს ამპლიტუდის, სიხშირისა და დროის ხანგრძლივობის მიხედვით უბნის სპეციფიკური ადგილობრივი მახასიათებლების გამო. ეს საკითხი მიკროდარაიონების მთავარი ამოცანაა.

გრუნტი ხასიათდება შემდეგი სეისმური პარამეტრებით: დომინანტური სიხშირე, Vs30 (განივი ტალღის საშუალო სიჩქარე 30 მეტრის სიღრმეზე) და გაძლიერების ფაქტორი. ამ ნაშრომში წარმოდგენილია გრუნტის კლასიფიკაცია დომინანტური სიხშირით, რომელიც მიღებულია გეოფიზიკური გაზომვებით, კერძოდ სეისმური ხმაურის ჩანაწერებით. გრუნტის მახასიათებელი ეს პარამეტრი მნიშვნელოვანია ლოკალური სეისმურობის დაზუსტებისთვის. ამ მიზნით საქართველოში პირველად იქნა გამოყენებული სეისმური ხმაურის ჩანაწერები.

საკვანძო სიტყვები: გარემოს ხმაური, წერტილოვანი სადგური, გრუნტის გადაადგილება, გაძლიერება, H/V ტექნიკა .

Исследование свойств грунтов для объектов критической инфраструктуры

Т. Шубладзе, Н. Церетели

Резюме

Грузия, как и весь Южный Кавказ, является тектонически и структурно сложным регионом. Она является одним из активных сегментов Альпийско-Гималайского пояса, поэтому важно оценить сейсмическую опасность для Грузии. На региональном уровне это оценивается путем применения вероятностного анализа сейсмической опасности, который определяет годовую вероятность превышения различных уровней землетрясений, определенных по интенсивности движения земли, таких как PGA или спектральные ускорения, соответствующие различным периодам повторяемости землетрясений, связанным с возможными будущими сценариями землетрясений для участка, представленного почвенными классами A в соответствии с EC8, Еврокод 8-EN 1998-1 (1998).

На местном уровне оценка сейсмической опасности осуществляется путем анализа геологических, геоморфологических, геотехнических и геофизических характеристик местности, так как хорошо установлено, что входящее сейсмическое движение может изменяться по амплитуде, частоте и длительности из-за специфических местных характеристик. Это является предметом микрозонального исследования.

Локальные характеристики конкретного участка представлены следующими параметрами: доминирующая частота Vs,30 (средняя скорость поперечной волны до глубины 30 метров) и коэффициент усиления. В этой работе мы представили результаты геофизических исследований, оценивающих местные сейсмические условия по доминирующей частоте для проектирования. С этой целью впервые в Грузии были использованы записи сейсмического шума.

Ключевые слова: Вибрация окружающей среды, одна станция, движение грунта, усиление, метод H/V.