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MICROTREMOR SURVEY AND SPECTRAL ANALYSES OF H/V RATIO FOR BAKU CITY (AZERBAIJAN)

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In this study, ground response analysis on different 255 sites in Baku city of Azerbaijan was done. The damage distribution is estimated on the basis of local site effects. Aiming to estimate local site effect, analysis of the ratio of horizontal to vertical (H/V) spectra of microtremor records was performed. The records are conducted with the Guralp CMG-5TD accelerometer and, with the Nakamura's approach, dynamic characteristics of surface ground are estimated. The maps showing the distribution of the amplification and resonance frequency for the grounds of Baku city were produced, which demonstrate variability and heterogeneity of ground characteristics in the city. The results can be used for urban seismic hazard assessment researches in the future.

Introduction

Seismic noise can be analyzed in different ways depending on the objective of the study. A popular analysis method is the H/V spectral ratio method. This method was first proposed by Nogoshi and Igarashi (1971) and years later it was summarized by Nakamura (1989). During the decade of the 1990´s almost 80% of the published works about seismic noise were using the H/V spectral ratio method (Bard, 1998; Bonnefoy-Claudet et al., 2006). It is very useful tool in identifying seismic ground motion amplification for earthquake hazard assessment, because it is very simple and economical in operation.

Baku is a fast growing megacity (availability of multi-stored buildings, residential places, industrial constructions, new roads, bridges, tunnels, fashionable hotels) that influences the economic and industrial developments in the country. This region has experienced many earthquakes since ancient times and faces severe seismic threats from the Caspian and Absheron seismic events. It lies in the zone VIII of seismic zoning map of Azerbaijan (MSK 64). Within the historical time period, peninsula, as well as, Baku city have shaken as a result of occurrences of a number of seismic events, such as 1842 Mashtagi earthquake with magnitude M=5 (25 km northward from Baku), 1983 Nardaran-Bilgyah earthquake with M=5, 1986, 1989 Caspian earthquakes with M=6.0-6.5, the last strong 2000 earthquake with M=6.3, which occurred southward from Baku city. Intensive city planning, erroneous land using, construction of many industrial and residential buildings, roads, tunnels, bridges, change of soil conditions due to the various geodynamic and seismic processes, lack of knowledge about modern ground characteristics of Baku city accentuate the necessity to apply microtremor measurements technique which is one of the useful method in investigating ground characteristics and estimating local sites effects, especially in the urbanized areas.

Geology of the area

The study area is located in the southeast side of the Greater Caucasus mega-anticlinorium. The region has specific geologic structures and tectonics.

Fig. 1 gives the tectonic and geological scheme of the area (Kadirov, 2000). In the region, mud-volcanic and diapir folds are widespread. The Tengi-Beshbarmag anticlinorium, Shahdag-Khizi, Zagatala-Govdag, Shamakha-Gobustan synclinorium, Absheron and the Lower Kur basins are the main tectonic structural elements (Shikhalibeyli, 1972). The area embraces the whole of the Absheron oil and gas-bearing region, a large part of the Shamakha-Gobustan region, some parts of the Baku Archipelago, the Lower Kur and near-Caspian oil and gas-bearing regions. Intensive subsidence in the Shamakha-Gobustan synclinorium began in the Cretaceous and Paleogene periods. The great thicknesses of the Paleogene-Neogene deposits and the clearly expressed boundaries of their occurrence, represented in the west by Zangi and in the east by Goradil thrusts, lend support to this subsidence. A comparison of geological and geophysical data from the Shamakha-Gobustan synclinorium indicates that the structural features of the Mesozoic and Cenozoic strata are discordant. The synclinorium is considered as a superimposed trough of complicated structure. Its south-west boundary is made up of the Lengebiz-Alyat anticline zone. The present structure of the Lengebiz-Alyat zone was formed in the late Pliocene-Quaternary period. The Absheron periclinal trough is superimposed in character and represents an extreme eastern structural element of the Greater Caucasus mega-anticlinorium. In the west, the trough is limited by the Yashma flexure, the origin of which is related to the Cenozoic subsidence of the Caspian basin. As a consequence, substantial sinking of the Absheron peninsula and of the North Absheron aquatorium, along with the islands and banks, occurred. Simultaneously, the eastern part of the Shamakha-Gobustan synclinorium the Jeyrankechmez depression, composed of Paleogene and Miocene sediments, was involved in this process.

According to the borehole and geophysical data, the depth of the Mesozoic top within the study area varies in the range of 1–10 km. In the central part of the Jeyrankechmez depression, the top of the Paleogene-Miocene complex lies below 3-4 km and that of the Mesozoic is within 8-10 km. The Lower Kur basin is the deepest among the basins of the Kur basin system. The major part of the Lower Kur basin is covered with Quaternary strata. The boundaries of the Lower Kur basin are the West Caspian fault and the Lengebiz-Alyat rise in the southwest and northeast, respectively. In the Lower Kur basin,

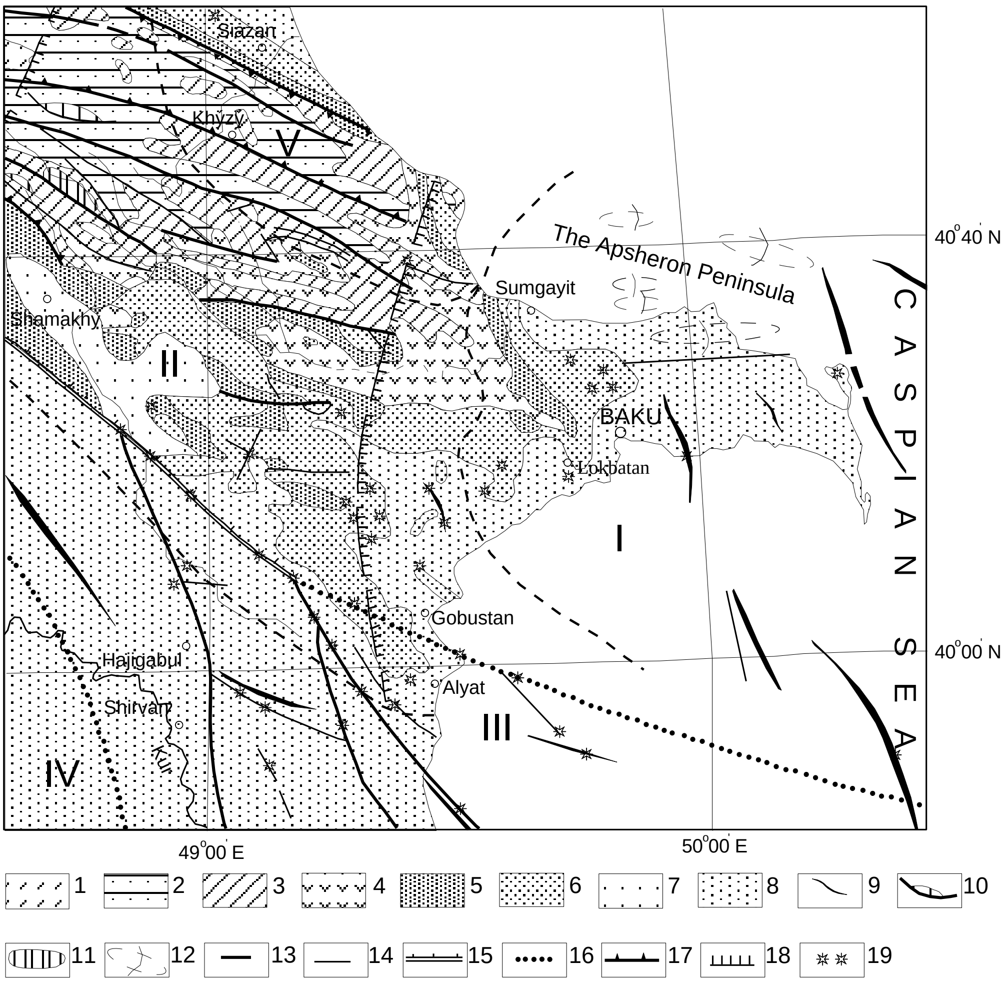


Figure 1. Tectonic and geological scheme of the study area. Alpine geosynclinals sub-complexes: 1 – early geosynclinals epoch, late geosynclinals epoch: 2 – lower epoch, 3 – middle epoch, 4 – upper epoch. Alpine orogenesis sub-complexes: 5 – early orogenesis sub-epoch, 6 – early orogenesis upper epoch o12., 7 – late orogenic epoch up to 800 m., 8 – late orogenic epoch 800 m and greater (O_2). Structural elements, fold types and dislocations with a break in continuity: 9 – axes of large anticlinal folds, 10 – scale-shaped folds, 11 – tectonic nappe, 12 – buried folds, 13 – normal faults with thousands of meters of amplitude, 14 – normal faults with hundreds of meters of amplitude, 15 – crustal faults manifested at the surface by thrusts and over faults, 16 – buried faults, 17 – thrusts and over faults with thousands of meters of amplitude, 18 – buried flexure, 19 – mud volcano. Oil- and gas-bearing regions: I – Absheron region, II – Shamakha-Gobustan region, III – Baku Archipelago, IV – Lower Kur region, V – near-Caspian region (Kadirov, 2000)

the thickness of the sedimentary pile is around 15 km, of which over 8 km is made up of the Pliocene-Quaternary sediments. The study area is an element of the Alpine folded belt of Eurasia. The Greater Caucasus and the Kur basin experienced tectonic evolution spanning the Late Proterozoic to the Anthropogenic period. In general, three periods are differentiated in the geological evolution of Azerbaijan: Baikalian, Hercynian and Alpine. The area along the Greater Caucasus axis and its south slope is supposed to belong to the Paleozoic geosyncline (Azizbekov et al., 1972).

Methodology

There are different methods to perform and interpret microtremor measurements, which require several instrumentation set-ups and assumptions. This study focuses on applications and interpretation of microtremors, with the emphasis on the method proposed by Nakamura (1989). Damages caused by the recent earthquakes are concluded as a direct result of local geological condition affecting the ground motion. Best approach for understanding ground conditions is through direct observation of seismic ground motion, but such studies are restricted to areas with relatively high rates of seismicity. Because of these restrictions in other methods, such as high rates of seismicity and the availability of an adequate reference site, non-reference site methods have been applied to site response studies. Microtremor is a very convenient tool to estimate the effect of surface geology on seismic motion without needing other geological information (Kanai et. al., 1954). Many observations and experiences on microtremor records show that microtremor consists of both body and surface waves, but there is no established theory concerning what kinds of wave motions the microtremor is made up from. In Nakamura (1989), the purpose of the author was the estimation of the amplification factor caused by multiply-refracted vertical incident SH waves. For this purpose, Rayleigh wave contained by microtremor was considered as noise and eliminated inside the H/V process. Nakamura (1989) gives theoretical definition of the H/V technique with multiple refraction of SH waves. On the other hand, there is a group of researchers who try to explain the peak of H/V ratio with the evidence of Rayleigh waves. As it is mentioned before, microtremor consists of many kinds of waves. Linking to the surface waves is based on the assumption that noise predominantly consists of surface waves. Figure 2 shows two of these examples for the microtremor records in Hakodate, Japan. It can be clearly seen from this figure that, energy of Rayleigh wave does not appear on the peak of H/V of Rayleigh wave. Rayleigh wave energy gets its maximum on later frequencies at minimum group velocity of Rayleigh wave and this is nearly equal to trough frequency which is almost two times of the H/V peak frequency (Nakamura, 2000).

From this view point, the Rayleigh wave plays as a noise and it is necessary to reject the effect of the Rayleigh wave. It is possible to understand that the surface layer behaves as a high-pass filter for the Rayleigh wave propagating in the surface layer. Rayleigh wave can not propagate in the frequency range under the predominant frequency of surface ground and can transmit the energy peak around the frequency of minimum group velocity.

Here microtremor is divided into two parts considering that it contains Rayleigh wave and other waves. Then, horizontal and vertical spectra on the surface ground of the sedimentary basin (H_f, V_f) can be written as follows (Nakamura, 2000):

$$H_f = A_h * H_b + H_s,\ \ V_f = A_v * V_b + V_s,$$

where A_h and A_v are amplification factor of horizontal and vertical motions of vertically incident body wave. H_b and V_b are spectra of horizontal and vertical motion in the basement under the basin (outcropped basin). H_s sand V_s are spectra of horizontal and vertical directions of Rayleigh waves.

Main waves consisting of microtremors are either body waves or Rayleigh waves, or depending on the location and other conditions they can be mixture of both waves. More explanation regarding Rayleigh waves can be found in Nakamura (1996).

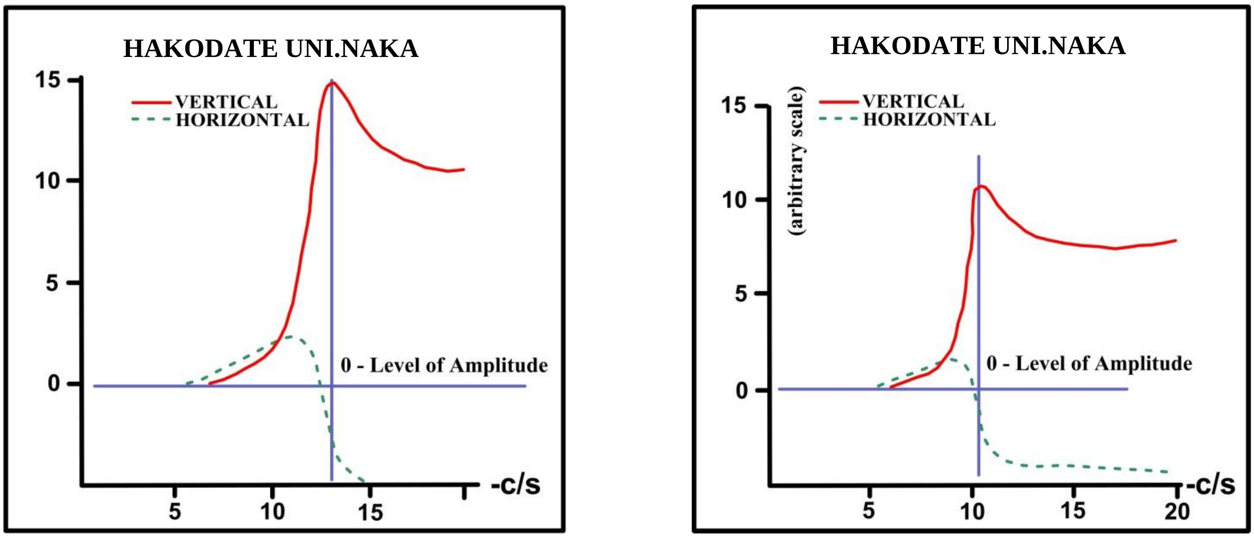
Microtremor survey and spectral analyses

The objective of the present study is to analyze microtremors for investigation of ground characteristics in Baku city by estimating local site effects through the H/V ratio technique. The parameters that were analyzed are amplitude spectra, soil classification, H/V spectral ratio, resonance frequency and amplification ratio in site location. In this study, microtremor measurements were done in 255 points in Baku city. The measurement points have been selected in such a way so that they could give a good coverage of the study area, a large selection of different quaternary sediments and sediment thicknesses (Kadirov et al., 2012). Recording duration is 30 minutes. Measurements have been conducted at the distance of every 500 m taking into account environmental impact after getting results of primary analyses observations have been repeated every 250 m.

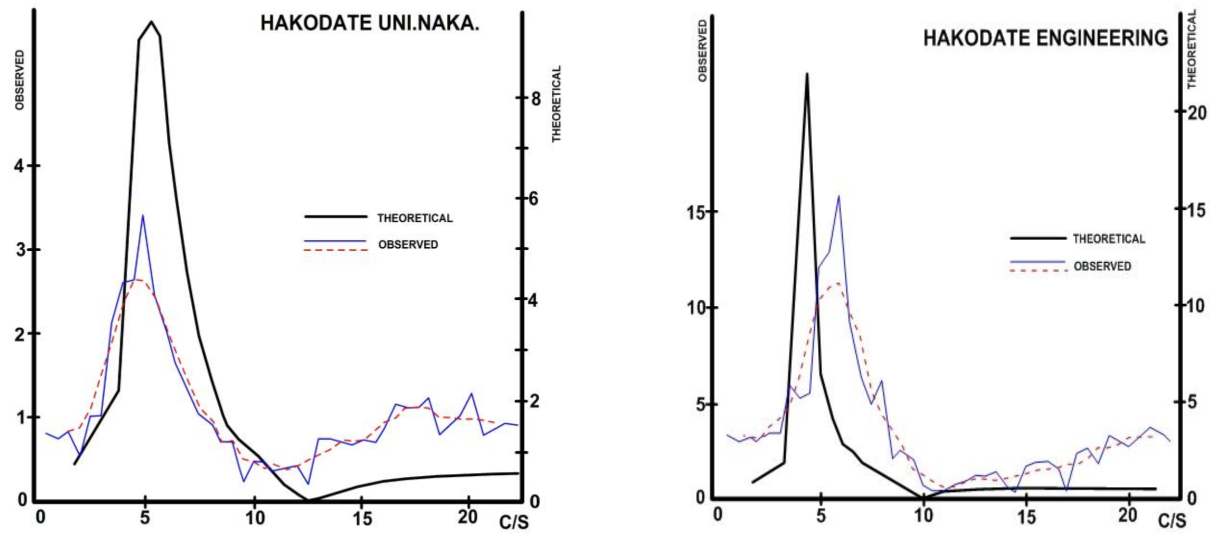
Figure 3 shows microtremor measurements points in throughout Baku city.

The resulting 255 H/V spectral ratios were systematically analyzed considering the recommendations proposed by the SESAME consortium (SESAME WP12 team 2005). Here we used the program “Matlab programming language” for H/V spectral analysis. (Figure 4 shows calculated of spectral analyzes for point 14, as an example).

The data processing for both data sets was as follows: each noise recording was divided into 30s window length. Each window was tapered at both ends with a 5% cosine taper and its Fast Fourier Transform (FFT) calculated. The FFT have been smoothed using a Konno-Ohmachi window (Konno and Ohmachi, 1998) fixing the parameter b to 20.



a)



b)

Figure 2. Example of horizontal and vertical components of rayleigh wave in Hakodate area, Japan (in (a) x axis represents velocity of S-waves; in (b) x axis represents frequency in unit, while y axis indicates H/V of Rayleigh wave)

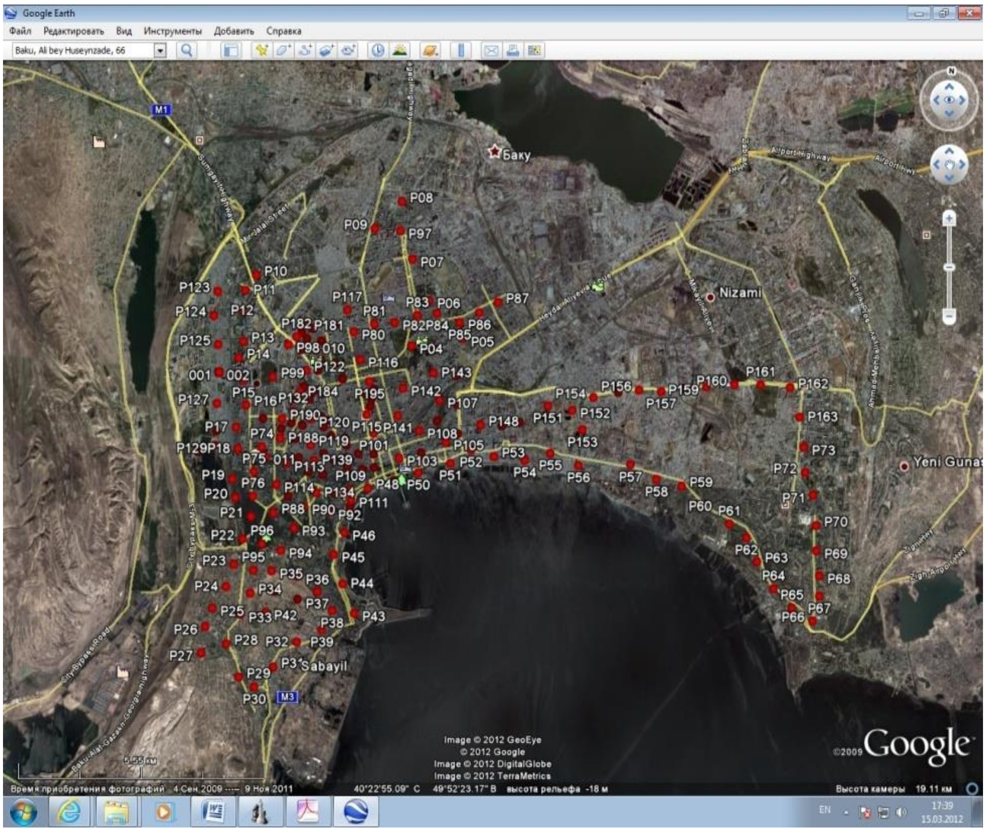


Figure 3. Measurements points

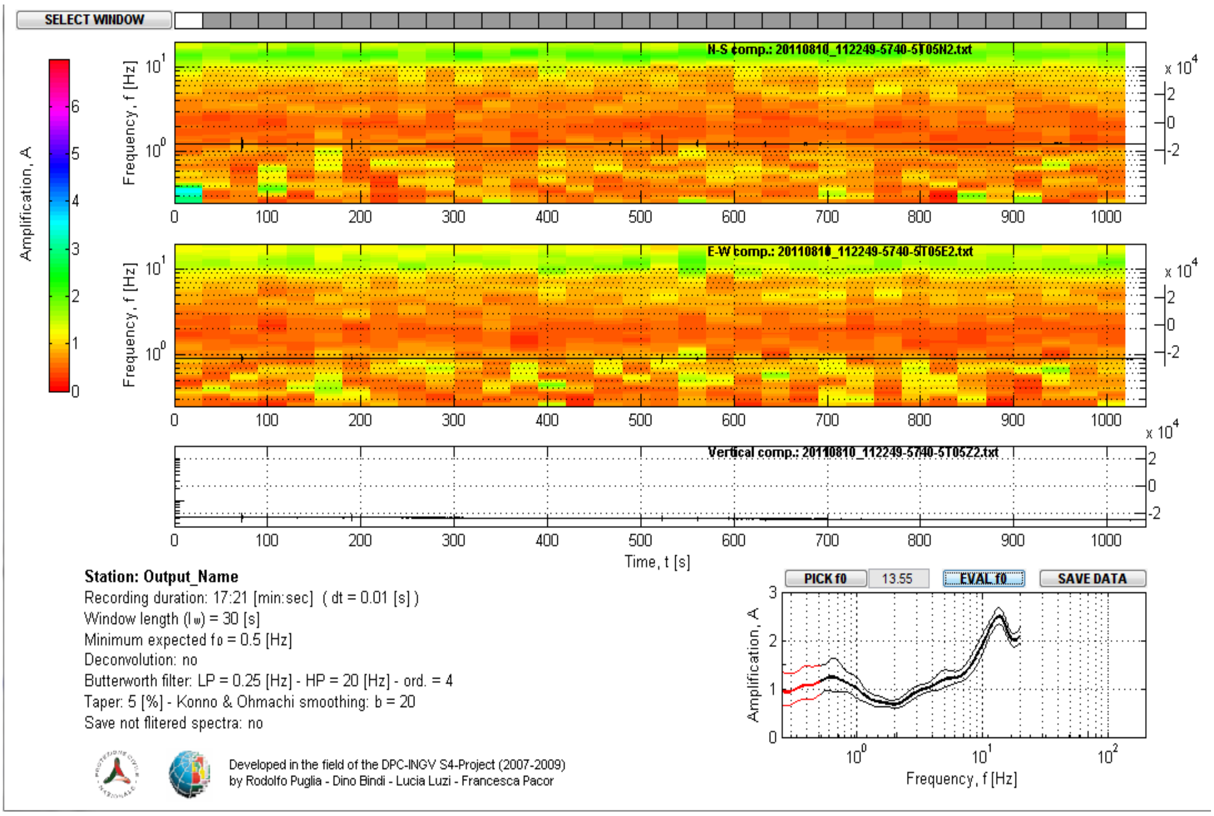


Figure 4. Spectral analyzes for point 14 (parametric entry was done by Ahadov B.)

Results

In the present study we have investigated the use of HVNSR analysis using microtremors in the Baku city to map the fundamental frequency and amplification factor of soils. Figure 5 and 6 demonstrate the map of the amplification factor and fundamental frequency of grounds in the Baku city, respectively. The results indicate that the ambient noise analysis can be an efficient tool for exploring soil conditions in urban areas. As a result of thorough investigation and observation of two above-mentioned maps, it was found out three zones with various ground conditions appeared over the area of study: hard soil, soft soil and intermediate type of soil. Preliminary analysis of amplitude-resonance properties of soil demonstrates that the larger part of the study area is covered by hard soil types. Intermediate type of soil can be observed in the north-western and north-eastern parts of the city. The soft soil types are mainly spread in the shoreline area and across the central part of the city. It is worth mentioning that with this approach, it is possible to reveal the influence of uncertainties on the resonance properties of the ground. Amplification factor ranges 0.6-4. Maximum amplification factor is observed in the western part. Fundamental frequency ranges 0.5Hz-9Hz. Also, maximum frequency is observed in the north – western part.

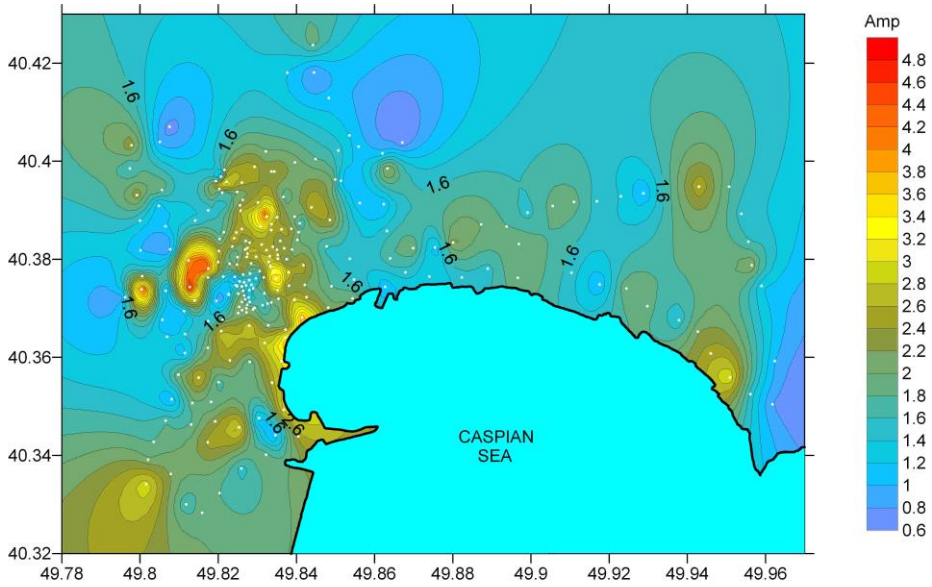


Figure 5. Map of the ground amplification distribution for Baku city

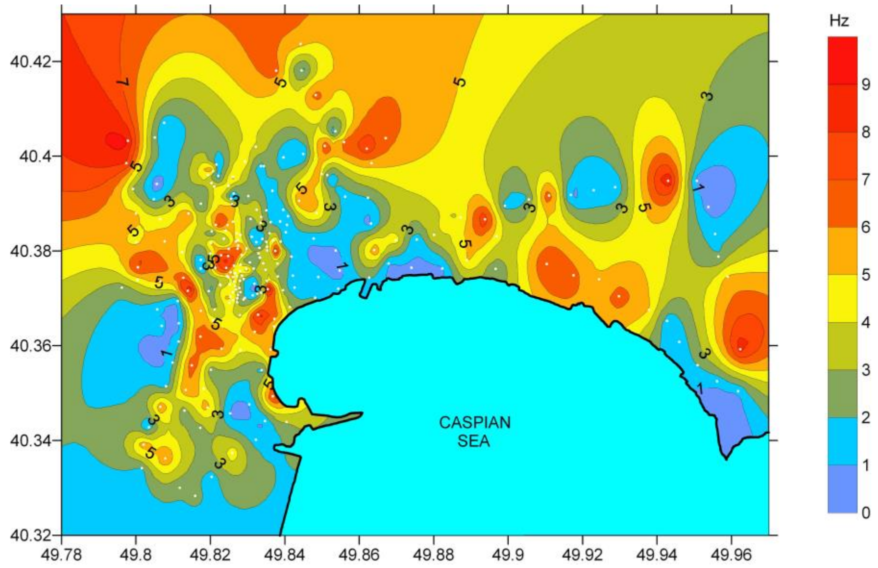


Figure 6. Map of fundamental frequency of resonance distribution for Baku city

In general, the site effects are usually associated with local subsurface conditions. From those two models, one can resume that where high frequency is observed at 5-8Hz, amplification normally dampens towards 0.6. This is most probably due to the heterogeneous content of the soils, such as within the hard rocks there might be existence of water-saturated soils, loose sediments (such as sands, sandy clays and clayey sands). Additionally, in those specific areas, more extensive measurements are necessary to perform in order to more clearly trace the obtained results of predominant frequency behavior and amplification factor correlated with the geological conditions of the study area.

Future plans

The resultant information obtained for the first time, will be used for preparation of the exact seismic hazard and risk maps and implementation of the effective plan to reduce the scale of destruction for Baku city.

Models of seismic hazard plotted up to the present time for Baku city have been prepared without information of real seismic motion, compiled theoretically, however for practical investigation it is necessary to use factual data. Besides, the establishment of 3D seismic models is very important for the city.

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REFERENCES

AZIZBEKOV, SH.A., AGABEKOV, M.G., GRIGORYANTS, B.V., SHIKALIBEYLI, E.SH., MAMEDOV, A.V. 1972. The history of the geological evolution. In: Azizbekov, Sh.A. Ed.: *Geology of the USSR, Azerbaijan vol. XLVII.* Nedra, Moscow, 441-503 (in Russian).

BARD, P.Y., JONATHAN, F. 1998. Springer Science & Business Media. 473 p.

BONNEFOY-CLAUDET, S., KÖHLER, A., CORNOU, C., WATHELET, M., BARD, P.Y. 2008. Effects of love waves on microtremor H/V Ratio. *Bull. seism. Soc. Am.*, 98(1), 288-300.

KADIROV, F.A. 2000. Application of the Hartley transform for interpretation of gravity anomalies in the Shamakhy-Gobustan and Absheron oil- and gas-bearing regions, Azerbaijan. *Journal of applied geophysics*, 45 (1), 49-61.

KADIROV, F., BABAYEV, G., GADIROV, A. 2012. Analysis of horizontal to vertical spectra of microseisms for Baku City. *Problems of Cybernetics and Informatics (PCI)*, 2012 IV International Conference.

KADIROV, F.A., BABAYEV, G.R., GADIROV, A.G., SAFAROV, R.T., MUKHTAROV, A.S. 2012. Microzonation of the Baku city using mikrotremor measurements. In the book: *Problems of reduction of natural hazards and risks*. International scientific and practical conference "GEORISK 2012". In 2 Vols. Volume 1. Moscow. Peoples' Friendship University of Russia (PFUR). 348, 94-98.

KANAI, K., TANAKA, T. 1954. Measurement of the microtremor. Bull. *Earthq. Res. Inst. Tokyo Univ.*, 32, 199-209.

KONNO, K., OHMACHI, T. 1998. Ground motion characteristics estimated from spectral ratio between horizontal and vertical components of microtremors. *Bull. Seism. Soc. Am.*, 88-1, 228-241.

NAKAMURA, Y. 1989. A method for dynamic characteristics estimation of subsurface using ambient noise on the ground surface. *QR Railway Tech. Res. Inst*., 30, 25-33.

NAKAMURA, Y. 1996. Real time information systems for seismic hazards mitigation UrEDAS, HERAS and PIC. *Quarterly Report of RTRI*, 37, 3, 112-127.

NAKAMURA, Y. 2000. Clear identification of fundamental idea of Nakamura's technique and its applications. 12WCSEE: 12th World conference on earthquake engineering, Auckland, New Zealand.

NOGOSHI, M., IGARASHI, T. 1971. On the amplitude characteristics of microtremor (Part 2). *Jour. Seism. Soc.* Japan, 24, 26-40 (in Japanese with English abstract).

SESAME EUROPEAN RESEARCH PROJECT WP12 – Deliverable D23.12 2004.

SHIKHALIBEYLI, E. 1996. Some problematic aspects of geological structures and tectonics of Azerbaijan. Elm. Baku.