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Serhii VERBYTSKYI[1a], Bohdan KUPLOVSKYI[1n], Vasyl PROKOPYSHYN[1c], Oleksandr STETSKIV[1d], Iryna NISHCHIMENKO[1e], Taras BRYCH[1f], Oleh KRUK[2]

[1] Department of Seismicity of the Carpathian Region at S. I. Subbotin Institute of Geophysics of the NAS of Ukraine, 27, Yaroslavenka Str., Lviv, 79011, Ukraine, tel.: +38(032)2706100, ORCID[1a]: https://orcid.org/0000-0003-1138-8648, ORCID[1b]: https://orcid.org/0000-0002-4221-5224, ORCID[1c]: https://orcid.org/0000-0003-2600-8767, ORCID[1d]: https://orcid.org/0000-0002-8414-7098, ORCID[1e]: https://orcid.org/0000-0003-4478-8875, ORCID[1f]: https://orcid.org/0000-0001-6853-1981, e-mail: sergever@gmail.com, bohdan_kuplyovsky@yahoo.com, pvasyl70@gmail.com, alexste0@gmail.com, iranlviv@gmail.com, taras_brych@hotmail.com

[2] Department of Software, Lviv Polytechnic National University, 12, Bandery Str., Lviv, 79013, Ukraine, ORCID[2]: https://orcid.org/0000-0001-6431-1287, e-mail: olehkruk@gmail.com

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EVALUATION OF SEISMIC SHAKING INTENSITY GAINS BY HIGH FREQUENCY MICROSEISM REGISTRATION METHOD (AS EXEMPLIFIED BY A DEVELOPABLE SITE IN UZHGOROD)

Objective. To refine seismic hazard parameters by registering high-frequency microseisms within the site under reconstruction in connection with the land plot enlargement of a plant intended for electronic components manufacturing. To quantify the estimated intensity of seismic shakings (in MSK-64 scale scores) accounting for the effects associated with local engineering and geological conditions at the study site. Methods. Seismic microzonation practical works at construction sites implies the application of short-period microseism registration method, which is considered to be one of the most efficient and unbiased instrumental SMZ methods when the field seismological studies are to be performed in a short period of time. The method relies on comparing parameters of soil micro-vibrations generated by natural and anthropogenic sources at the studied and the reference sites. At that, the soil is regarded as a filter capable of modifying the amplitude and phase oscillation spectra of seismic waves hitting the sedimentary cover basement. The seismic intensity gains were determined by comparing the amplitudes of soil oscillations at registration points over several sections of the site and at a reference point. Microseisms were recorded by using two identical three-channel digital seismic stations DAS-05 being the newest ones out of the model series of automatic seismic stations developed at S. I. Subbotin Institute of Geophysics of the NAS of Ukraine. VEGIK seismometers were used as seismometers. Results. Microseismic oscillation recording analysis has revealed that the main contribution to the formation of a wave field is due to the urban background disturbances falling within the frequency range of f = 8.0 – 18.0 Hz, as well as low-frequency natural oceanic effects amounting to f = 0.4–8.0 Hz while high-frequency vibrations are caused by anthropogenic factors amounting to f = 18.0–27.0 Hz (Fig. 3). Data of synchronous 24-hour microseism registering have indicated a sufficiently high stability of the amplitude level and frequency composition of microseismic oscillations, which suggests that the microseismic processes approximate stationary ones, provided that non-stationary events are removed from records. Plots of seismic intensity gain values at different frequencies caused by soil conditions at the studied site, determined according to the relation of averaged microseismic amplitude spectra both at the studied and reference site, are shown in Fig. 4. The average estimates of seismic intensity gains in the frequency range of 0.1–20.0 Hz for the construction site soil conditions, calculated with respect to microseismic spectral densities per all three vibration components, are presented in Table 1. The seismic intensity gain in relation to the initial (background) one for the engineering and geological conditions of the site equals to ΔI_r = -0.21. Scientific novelty. Given the amplitude ratio and amplitude spectra of microseisms recorded at different sites and at the reference point, refined parameters of seismic hazards for the developable site have been obtained with consideration of the local soil conditions effects. Evaluation ratings of seismic shaking calculated intensity (in MSK-64 scale scores) based on effects associated with the local engineering and geological conditions of the study site have been provided. Practical significance. Construction site SMZ yields updated values of seismic forces relative to the general seismic zonation of the country, which allows taking into account possible gain in seismic severity at the design stage of earthquake-proof construction. Consideration of SMZ results at construction of engineering structures prevents human casualties and reduces economic losses in case of seismic manifestations.

Key words: seismic microzonation (SMZ), high frequency microseism registration method, seismic intensity, seismic hazard, amplitude-frequency response (AFR).

Introduction

An extensive experience of seismological surveys has proven that local geological conditions are a major factor when it comes to the magnitude and extent of earthquake-induced damages. The importance of keeping said conditions in mind when evaluating seismic hazards and parameters of possible seismic effects becomes obvious even when individual construction sites and structures are involved since cases of complete collapse of either of two closely located houses built using the same safety factor are quite common [Kendzera, 2015; Kuplovsky, & Brych, 2018].

Until the seventies of the last century, it was thought that the main danger in the territory of Ukraine was caused only by strong sub-crustal earthquakes generated in the Vrancea zone. Local seismicity was studied scarcely. The seismic network was not sufficient to determine not only the location of foci of weak local earthquakes, but also to establish their mechanism. Recently, the number of seismic stations has increased. The results of local seismicity studies on the territory of the East-European Platform confirmed that within it, as well as within other ancient platforms, powerful earthquakes may occur although much less frequently than in seismic belts of the planet [Kutas, et al., 2007].

It has been established that seismic hazards of a construction site is determined by intense sub-crustal earthquakes originated in the seismically active Vrancea zone located at the junction of the Eastern and Southern Carpathians with the Pre-Carpathian Depression within the territory of Romania, as well as "local" earthquakes, which may occur in the immediate vicinity of the study site and be associated with tectonic disturbances in the East European platform. In order to determine quantitative parameters of seismic hazards for the study site we calculated the value of seismic shaking refined intensity (accurate up to 0.01 scores) for earthquakes occurring in the Vrancea zone (Romania) and earthquakes occurring in local potential seismically active zones [Kuplovskyi, et al., 2020].

According to maps reflecting general seismic zonation of the territory of Ukraine, i.e. ZSR-2004-C, which are an integral part of DBN B.1.1-12:2014 Construction in Seismic Regions of Ukraine, the standard intensity attributed to "average" soil conditions in the city of Uzhgorod (2nd grade) is $\mathbf{I_0 = 8}$ for the recurrence period **T = 5.000** years and probability **P = 99 %** not exceeding said intensity in the next 50 years (map ZSR-2004-C) [DBN B.1.1-12:2014…, 2014]. The background intensity $\mathbf{I_0}$ is specified for the 2nd grade soils according to their seismic properties. In this work, we refine the seismic activity taking into account site soil conditions through a method complying with the requirements of DBN B.1.1-12:2014, namely through the registration of high-frequency microseisms.

Objective

To refine seismic hazard parameters by registring high-frequency microseisms within the site under reconstruction in connection with the land plot enlargement of a plant intended for electronic components manufacturing. To quantify the estimated intensity of seismic shakings (in MSK-64 scale scores) accounting for the effects associated with local engineering and geological conditions at the study site.

Methods

Seismic microzonation practical works at construction sites implies the application of short-period microseism registration method [DBN B.1.1-12: 2014…, 2014; RSN 60-86, 1986; RSN 65-87, 1987], which is considered to be one of the most efficient and unbiased instrumental SMZ methods when the field seismological studies are to be performed within a short period of time. The method relies on comparing parameters of soil micro-oscillations generated by natural and anthropogenic sources at the study and the reference sites. At that, the soil is regarded as a filter capable of modifying the amplitude and phase oscillation spectra of seismic waves hitting the sedimentary cover basement. The seismic intensity gains were determined by comparing the amplitudes of soil oscillations at registration points over several sections of the site and at a reference point.

Equipment and field survey methodology

Microseisms were recorded by using two identical three-channel digital seismic stations DAS-05 being the newest ones out of the model series of automatic seismic stations developed at S. I. Subbotin Institute of Geophysics of the NAS of Ukraine [Verbytskyi, et al., 2006]. VEGIK seismometers were used as seismometers.

DAS-05 seismic station provides the following:

- registration of the full vector of seismic vibrations in the dynamic range of 140 dB;
- registration of frequency of measured data in the range of 0.012–100 Hz;
- off-line operation period of the equipment using rechargeable batteries is not less than 24 hours;
- calibration of seismic channels, which allows determining the amplitude and phase frequency characteristics of seismic channels with an accuracy of up to 5 % in the frequency range of 0.01–50 Hz.

Amplitude-frequency and phase-frequency characteristics (FC) of measuring channels are shown in Fig. 1. They are determined by means of a special vibration platform. The FC stability is controlled by registering the measuring channel response to a special calibration pulse supplied into a seismic detector coil [Oppenheim, et al., 1983], thus simulating the acceleration of seismic receiver base ("soil") vibrations.

Using a complex FC for the acceleration $\boldsymbol{B_v(s)}$, where $s = j*\omega$, $j = \sqrt{-1}$, ω is the angular velocity, $\omega = 2*\pi*f$, where $\boldsymbol{f}$ is the regular frequency, the displacement frequencies $\boldsymbol{D_v(s)}$ and velocity frequencies $\boldsymbol{H_v(s)}$ can be easily determined:

$$D_v(s) = B_v(s)/s, \qquad H_v(s) = B_v(s)/s.$$

Since there are no preliminary data on spatial and temporal variations of a microseism field available for the study site territory, at the stage of reconnaissance survey we figured out conditions ensuring the maximum possible compliance of observations with standard requirements. For this purpose, ongoing registration of short-period microseismic oscillations was performed at the construction site and at the reference point located as close to the study site as possible (see Fig. 2). It should be noted that soils of all three sites fall in the 2nd grade according to their seismic properties.

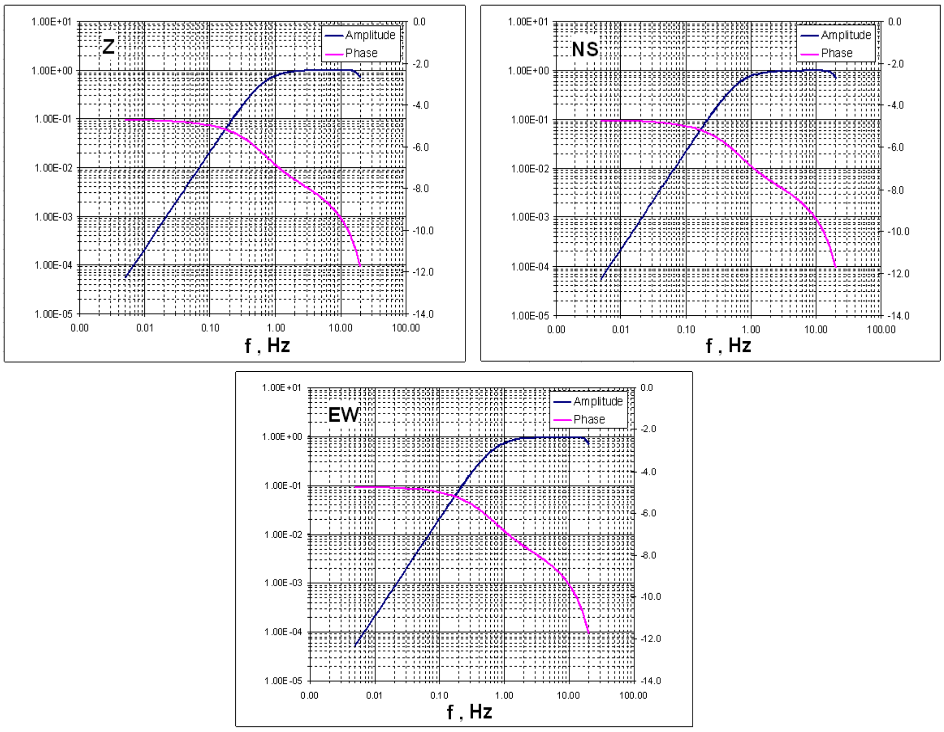

Fig. 1. Amplitude-frequency and phase-frequency characteristics of vertical (Z) and two horizontal (NS and EW) DAS-05 measuring channels.

Fig. 2. Location of the reference point (BASE) where soils are classified as the 2nd grade in terms of their seismic properties.

PNT1 – Location of seismic instrumentation for long term monitoring of seismic vibrations for the purposes of site SMZ by recording earthquakes, explosions and high frequency microseisms.

Benchmark soil selection

Pursuant to RSN-60-86 [*RSN 60-86, 1986*], a benchmark soil similar in seismic properties to the 2nd grade soils, to which the refined seismic hazard value of the study site territory applies, should be selected for evaluating the seismicity gain. Benchmark soil parameters are required for the site SMZ through seismic impedance method and short-period microseism registration method.

Based on the results of analysis of engineering and geological survey data as well as field engineering and geological tests of soil samples, an area encompassing a benchmark soil was identified. It is located outside the site within the Uzh River bedrock terrace, where weathered crystalline basement rocks terminate at the surface (Fig. 2) [Kuplovskyi, et al., 2020].

Results

During fieldworks, the microseism registration was carried out at the reference point, which soils are classified as the 2nd grade in terms of their seismic properties (the reference point), located outside the study construction site, as well as at one point within the study site.

When determining seismic intensity gains at different points of the study site relative to the reference site and taking into account the experience of similar studies [Kendzera, et al., 1989] we made extended (2–8 hours) evening and night synchronous records of microseisms at the reference point and at points within the study site by using DAS-05 seismic stations. Monitoring was performed during the sunset-to-sunrise period because of the relative stability of amplitude-frequency composition of microseisms and the minimum level of technogenic interference in the evening and night time. The microseismic spectrum at the site and at the reference point adequately covered the entire specific frequency range, which allowed us to obtain confident values of the relative (to the reference point) frequency response from the observation point at the site. Typical peaks of Fourier amplitude spectrum microseism recordings, which can be seen in Fig. 3, correspond to the prevailing periods of the site soil oscillations at the observation point.

The results of high-frequency microseisms monitoring coincide in magnitude and spectral composition at all observation points.

The analysis of microseismic oscillation records has shown that the main contribution into the formation of a wave field is made by oscillations caused by urban background noise over the frequency range $f = 8.0–18.0$ Hz and by low-frequency natural oceanic effects $f = 0.4–8.0$ Hz while high-frequency oscillations are caused by anthropogenic factors $f = 18.0–27.0$ Hz (Fig. 3). Data of synchronous 24-hour registration of microseisms indicate a sufficiently high stability of the amplitude level and frequency composition of microseismic oscillations, which allows drawing a conclusion on the similarity of the microseismic process to a stationary one, provided nonstationary events are eliminated from the records.

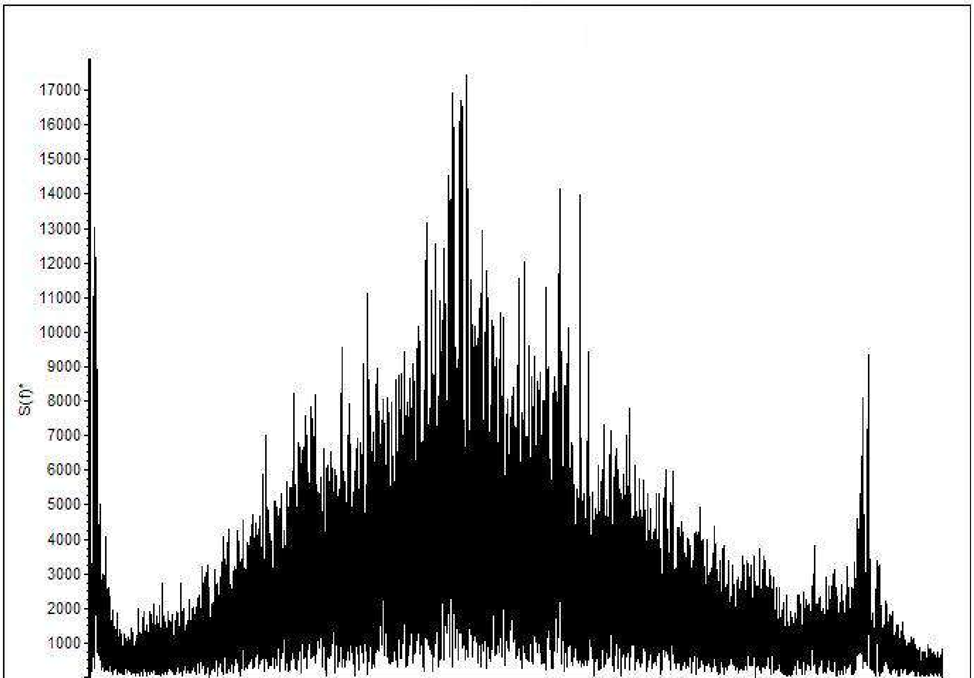

Fig. 3. Example of a microseism EW-component recorded spectrum over a 2-hour period at the construction site.

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Seismic intensity gain by relation of amplitude and amplitude spectra of microseisms registered at different locations within the site and at the reference point

The seismic intensity gain (***ΔI_r***) derived from short-period microseism recordings was estimated as the relation of amplitude spectra of microseisms recorded at different sites and at the reference point.

In determining **ΔI_r** by this method, for each recorded component and each observation point, the amplitude spectra were calculated by a computational program that implements a fast Fourier transform algorithm, from which relative frequency characteristics and seismic intensity gains were received.

In [Kendzera, et al., 1989] it has been shown that in order to obtain a solid result firstly it is necessary to construct smoothed averaged spectra of vibrations caught at the study sites and at the reference point from a set of individual spectra of synchronous records and then, by dividing spectra, to obtain the corresponding values of relative frequency characteristics.

The relative amplitude-frequency response (AFR) of soils for a given point was determined as the quotient of vibration spectrum averaged over several vibration spectrum recordings at the study site and the averaged spectrum of vibration recordings at the reference point.

The results of calculation of relative amplitude-frequency characteristics of soils were used to evaluate seismic intensity gains according to the formula [RSN 60–86, 1986]:

$$\Delta I_r = 2\lg (S_i(\omega)/ S_{em}(\omega)),$$

where **$S_{em}(\omega)$** i **$S_i(\omega)$** are microseism amplitude Fourier spectra in different components recorded both at the reference point and at the study site.

Plots of seismic intensity gains at different frequencies caused by soil conditions at the study site, as determined from the relation of averaged amplitude spectra of microseisms at the site and that at the reference point, are shown in Fig. 4.

Average estimates of seismic intensity gains in the frequency range 0.1–20.0 Hz for soil conditions of the construction site, calculated as the relation of spectral densities of microseisms in all three vibration components, are presented in Table 1. The **ΔI_r** value was calculated according to the relation:

$$\Delta I_r = \sqrt{\tfrac{1}{3}(\Delta I_{EW}^2 + \Delta I_{NS}^2 + \Delta I_Z^2)}\ .$$

Table 1

Seismic intensity gain calculated pursuant to the microseism registration method

Average seismic intensity gain in scores across the oscillation components:			ΔI_r
EW	*NS*	*Z*	
-0.03	**-0.35**	**-0.12**	**-0.21**

The average seismic intensity gain, relative to the initial (background) one, calculated using the icroseism registration method by reference to engineering and geological conditions of the site is as follows: **ΔI_r = -0.21**.

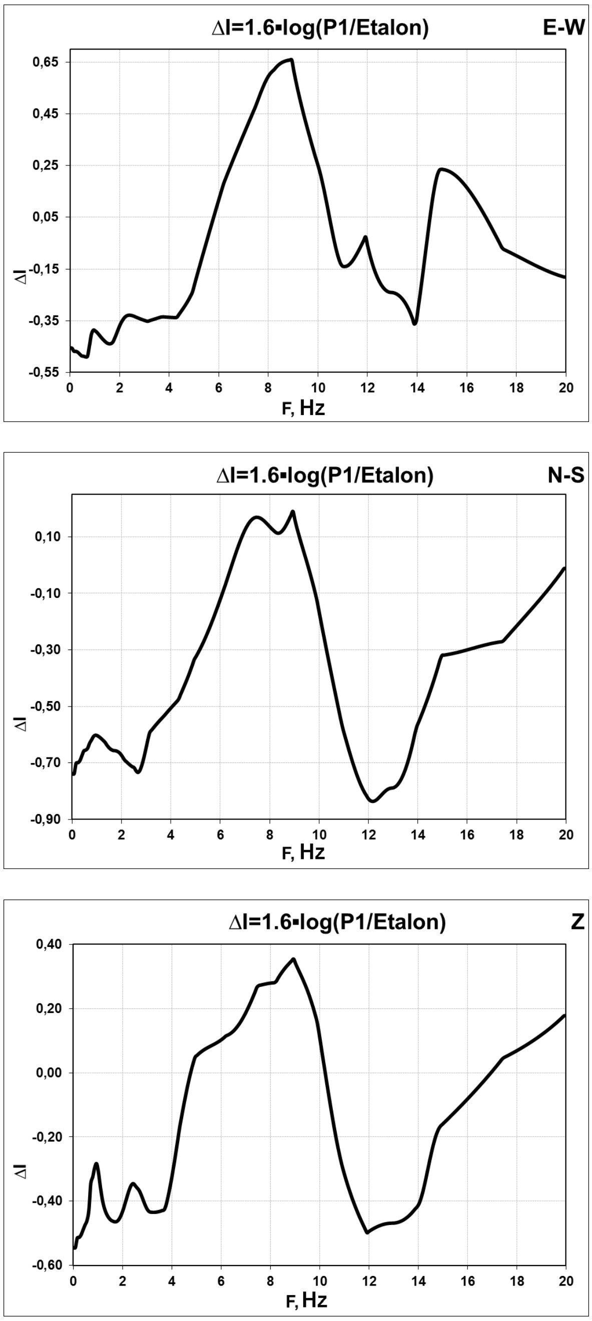

Fig. 4. Plots of ***$F = \omega/2\pi$*** frequency distribution of the seismic intensity gain (relative to the reference point) at the construction site in MSK-64 scale scores in relation to oscillation components: -EW, -NS, -Z.

Scientific novelty and practical significance

Based on the relation of amplitudes and amplitude spectra of microseisms recorded in different areas of the site and at the reference point, the refined parameters of seismic hazards for the construction site, taking into account the effects of local soil conditions, have been determined.

The evaluation of seismic shaking calculated intensity (in MSK-64 scale scores) has been provided taking into account the effects associated with local engineering and geological conditions of the study site.

SMZ of construction sites provides for obtaining specified values of seismic effects considering general seismic zoning of the country and allows taking into account exact values of seismic manifestations at the stage of seismic-proof construction design. Consideration of SMZ results during construction of engineering structures allows avoiding human casualties and reducing economic losses for the region in case of seismic shaking events.

Conclusions

According to map ZSR-2004-C the normative (background or input) intensity of seismic shaking of the construction site amounts to $\boldsymbol{I_N} = \mathbf{8}$ per MSK-64 scale. Earthquakes with such intensity on the territory of Uzhgorod may occur once in 5.000 years (seismic risk is 1 %). The eight-scored seismic shaking intensity will not be exceeded in the next 50 years with 99 % probability.

The analysis of results of instrumental works on seismic microzonation has demonstrated that the seismic intensity gain (magnitude) $\Delta\boldsymbol{I}$, relative to the normative (background) one, considering local engineering-geological conditions of the study site is $\Delta\boldsymbol{I_r} = \mathbf{-0.21}$.

The value of ***I*** should be rounded up to an integer, since the current standard DBN B.1.1-12:2014 does not require fractional values of seismic intensity, which is determined according to DSTU-B.1.1-28_2010 *Seismic* Intensity Scale, MSK-64 scale and its later versions, including the European Macroseismic Scale EMS-98 [Seismic intensity scale., 2011]. Thus, the calculated value of seismic intensity for the study site taking into account the effect of local soil conditions is **I = 8** as per MSK-64 scale and the tolerable seismic risk is 1 % (seismic gap is 5,000 years).

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Сергій ВЕРБИЦЬКИЙ[1], Богдан КУПЛЬОВСЬКИЙ[1], Василь ПРОКОПИШИН[1], Олександр СТЕЦЬКІВ[1], Ірина НІЩІМЕНКО[1], Тарас БРИЧ[1], Олег КРУК[2]

[1] Відділ сейсмічності Карпатського регіону Інституту геофізики ім. С. І. Субботіна НАН України, вул. Ярославенка, 27, Львів, 79011, Україна, тел. +38(032)2706100, ел. пошта: sergever@gmail.com, bohdan_kuplyovsky@yahoo.com, pvasyl70@gmail.com, alexste0@gmail.com, iranlviv@gmail.com, taras_brych@hotmail.com
[2] Кафедра програмного забезпечення Національний університет "Львівська політехніка", вул. С. Бандери, 12, Львів, 79013, Україна, ел. пошта: olehkruk@gmail.com

РОЗРАХУНОК ПРИРОСТІВ ІНТЕНСИВНОСТІ СЕЙСМІЧНИХ СТРУШУВАНЬ МЕТОДОМ РЕЄСТРАЦІЇ ВИСОКОЧАСТОТНИХ МІКРОСЕЙСМ (НА ПРИКЛАДІ МАЙДАНЧИКА ЗАБУДОВИ В м. УЖГОРОД)

Мета. Отримати уточнені параметри сейсмічної небезпеки майданчика під реконструкцію з розширенням заводу по виробництву компонентів для електронної промисловості методом реєстрації високочастотних мікросейсмів. Дати кількісну оцінку розрахункової інтенсивності сейсмічних струшувань (в балах шкали MSK-64) з урахуванням ефектів, пов'язаних з локальними інженерно-геологічними умовами досліджуваного майданчика. Методика. Виконання практичних робіт з сейсмічного мікрорайонування будівельних майданчиків передбачає використання методу реєстрації короткоперіодних мікросейсм, який вважається одним з найбільш ефективних і об'єктивних інструментальних методів СМР при малих термінах проведення польових сейсмологічних досліджень. Застосування методу ґрунтується на порівнянні параметрів мікроколивань ґрунтів, які збуджуються джерелами природного і техногенного походження на досліджуваній і еталонній ділянках. Ґрунт при цьому розглядається як фільтр, який може змінювати амплітудний і фазовий спектри коливань в сейсмічних хвилях, падаючих на підошву осадового чохла. Прирости сейсмічної інтенсивності визначаються за результатами порівняння амплітуд коливань ґрунтів в пунктах реєстрації на різних ділянках майданчика і на еталонному пункті. Запис мікросейсм виконувався двома ідентичними триканальними цифровими сейсмічними станціями DAS-05, найновішими з модельного ряду автоматичних сейсмостанцій, розроблених в Інституті геофізики ім. С. І. Субботіна НАН України. У якості сейсмоприймачів використовувалися сейсмометри "ВЕГІК". Результати. Аналіз записів мікросейсмічних коливань показав, що основний внесок у формування хвильового поля дають коливання, обумовлені міськими фоновими завадами в діапазоні частот f = 8,0–18,0 Гц, а також низькочастотними природними океанічними впливами f = 0,4–8,0 Гц, високочастотні коливання обумовлені техногенними чинниками f = 18,0–27,0 Гц (рис. 3). Матеріали синхронних цілодобових реєстрацій мікросейсм свідчать про досить високу стабільність амплітудного рівня і частотного складу мікросейсмічних коливань, що дозволяє зробити висновок про близькість мікросейсмічного процесу до стаціонарного, при умові усунення з записів нестаціонарних подій. Графіки значень приросту сейсмічної інтенсивності на різних частотах за рахунок ґрунтових умов досліджуваного майданчика, встановлені за співвідношенням усереднених амплітудних спектрів мікросейсм на ньому і на еталонному пункті, показано на рис. 4. Середні в частотному діапазоні 0,1–20,0 Гц оцінки приростів сейсмічної інтенсивності для ґрунтових умов будівельного майданчика, отримані по відношенню спектральних густин мікросейсм на всіх трьох складових коливань, представлені в табл. 1. Приріст сейсмічної бальності, відносно початкової (фонової), для інженерно-геологічних умов ділянки складає: ΔI_r = -0,21 *бала*. Наукова новизна. За співвідношенням амплітуд і амплітудних спектрів мікросейсм, зареєстрованих на різних ділянках майданчика і на еталонному пункті, отримані уточнені параметри сейсмічної небезпеки майданчика забудови, які враховують вплив локальних ґрунтових умов. Дана кількісна оцінка розрахункової інтенсивності сейсмічних струшувань (в балах шкали MSK-64) з урахуванням ефектів, пов'язаних з локальними інженерно-геологічними умовами досліджуваного майданчика. Практична значущість. СМР майданчиків будівництва дає уточнені значення сейсмічних впливів відносно загального сейсмічного районування країни, що дозволяє на етапі проектування сейсмостійкого будівництва враховувати можливий приріст сейсмічної бальності. Врахування результатів СМР при будівництві інженерних конструкцій дозволяє уникнути людських жертв і зменшити економічні втрати при сейсмічних проявах.

Ключові слова: сейсмічне мікрорайонування (СМР), метод реєстрації високочастотних мікросейсм, сейсмічна інтенсивність, сейсмічна небезпека, амплітудно-частотна характеристика (АЧХ).

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