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SEISMIC ZONING OF KYIV IN PHYSICAL PARAMETERS OF SOIL OSCILLATIONS

Purpose. The paper substantiates the need for building seismic zoning maps of Kyiv in the physical parameters of ground motions: peak ground accelerations (PGA), peak ground velocities (PGV) or peak ground displacements (PGD). They are the basis for the effective use of methods for calculating seismic loads on buildings, structures and individual responsible constructions. An intermediate stage in the creation of such maps is the development of a map of seismic zoning the territory of Kyiv in terms of relative integral estimates of spectral increments in seismic soil oscillations, arising from the influence of the peculiarities of the distribution of physical parameters of soils. The intermediate map gives the distribution over the city territory of a quantitative assessment of the influence of the soil spectral characteristics l on the seismic hazard, expressed in systemic physical quantities. **Methodology.** An analytical-empirical approach to mapping the seismic hazard of territories is applied. The method of seismic-geological analogies helped to identify areas (taxonomic zones) within the territory of Kyiv. In these areas, the seismic effect can differ significantly both in physical parameters (displacement, speed, acceleration) and the ability of soil strata to significantly affect the spectral characteristics of the soil. **Results.** For each taxonomic zone, a computational seismic-geological model with inelastic deformation parameters has been built,.The model allows taking into account the occurrence of nonlinear effects under significant seismic influences. Equivalent linear modeling was used to calculate the frequency response of seismic-geological soil models for each taxonomic zone. The averaged frequency response for the ground conditions of the territory of Kyiv was calculated. A map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value for the territory of Kyiv was built. The integral spectral amplification is the area of the subspectral function. The study conducted a dynamic analysis of the propagation of seismic oscillations in seismic-geological models. It also illustrated the influence of the upper sedimentary layer on the value of the peak ground acceleration PGA on the free surface. **Originality.** For the first time within the territory of Kyiv, areas (taxonomic zones) have been identified, where the response of the soil to the seismic effect will differ. We constructed a map of the distribution of the deviation of the integral amplification of seismic oscillations by soils from the average value for the territory of Kyiv. **Practical significance.** The map of seismic zoning of Kyiv in amplitude terms of soil oscillations is proposed to be used when applying the spectral method for calculating an emergency combination of loads, taking into account seismic effects, to determine the value of the calculated relative ground accelerations of the construction site under study.

Key words: seismic zoning; seismic hazard, peak ground acceleration; earthquake-resistant construction.

Introduction

The modern concept of seismic protection of the population and important objects is not in predicting an earthquake time, but in the seismic design of new and strengthening existing buildings and structures capable of minimizing the consequences of future earthquakes. Measures to ensure seismic protection on the territory of Ukraine are regulated by the “State Building Standards of Ukraine” – SBS V.1.1-12: 2014 [SBS V.1.1-12: 2014].

An integral part of the norms is general seismic zoning maps (GSZ). They reflect the results of seismic hazard zoning in terms of seismic intensity (points), which with a probability of 90 % (map A), 95 % (map B), and 99 % (map C) will not be exceeded in the next 50 years. The data presented on the OSR maps were obtained by statistical analysis of the available macroseismic, instrumental seismological, geological-geophysical, tectonic and geodynamic materials listed in the terms of seismological hazard.

Seismic zoning of the territory (displaying on maps of areas of the territory that are seismically homogeneous and with the same values of the selected parameters of seismic hazard) is a complex and responsible problem of modern seismology since it affects the social, economic, and environmental components of sustainable development. The scientific problem is that seismic hazard prediction belongs to the category of predictions based on incomplete information [Ulomov, Shumilina, 1999].

The map A, B, or C from the Appendix B of SBS V.1.1-12: 2014 and the calculation method are used to assess the seismic hazard of the territory, depending on the class of responsibility of the object under study.

In addition to the results of the GSZ, we use the refinement of the seismic hazard parameters aimed at practical determination of these parameters of the territory of the location of a particular object.They are obtained on the basis of maps of detailed seismic zoning (DSZ) and seismic microzoning (SMZ).

The work on the DSZ helps to clarify the effects that may arise at the construction (operational) site from earthquakes associated with nearby potentially seismically active zones. Their influence could not be taken into account when developing the GSZ maps.

Works on SMZ make it possible to take into account the increase in seismic intensity from close and powerful distant earthquake foci. It arises due to the influence of local features of the upper layers of the geological section of the soil layer directly under the construction site. Relatively homogeneous areas are displayed on SMZ maps.Refined values of seismic intensity (points) are set for them.In addition, model predicted values of the time variable behavior of the full vector of surface seismic oscillations of the soil layer are constructed in terms of acceleration (accelerogram), velocity (velocigrams) and displacement (seismograms). At the same time, it is taken into account that soil oscillations on the site will differ significantly during earthquakes with foci in close and distant seismically active zones. For sites on the territory of Ukraine, such a remote seismically active zone is the Vrancea zone. The earthquakes from it shake almost the entire territory of Ukraine with an intensity of 9 ÷ 4 points on the MSK-64 macroseismic scale [SBS V.1.1-12: 2014].

In the period 1960-2000, most countries switched to seismic zoning in terms of amplitude parameters of oscillations [Gusev, 2011a], namely, in peak ground accelerations (Europe, Japan, China) or in the levels of the response spectrum (USA, Canada). The use of these parameters by designers to ensure the seismic resistance of buildings and structures is correct in comparison with the use of non-system units – seismic intensity in the points.

Calculations of critical structures for an emergency combination of various (including seismological) loads are performed on models of buildings and structures using: the spectral method, the direct dynamic method or the nonlinear static calculation method [SBS V.1.1–12: 2014].

The most reliable of the above is the direct dynamic method for calculating seismic stresses in models. It takes into account the features of the shape, the distribution of the physical parameters of the model, the physical nonlinearity of materials and allows comparing the calculated predicted seismic stresses with the permissible design stresses in the soil base and critical structures of buildings and structures.

To apply the direct dynamic method, work is carried out on seismic microzoning and calculated accelerograms are generated for the soil of a specific construction site. The calculated accelerograms take into account the peculiarities of the spectral characteristics of the soil layer of the investigated construction site.

Specialists in seismic design and construction can always create reliable models of seismic-resistant buildings and structures protected from predicted earthquakes on condition of sufficiently accurate and justified quantitative parameters of the seismic hazard of a construction site. . This happens by determining additional seismic loads during design earthquakes on critical structures of buildings and structures, which should not exceed the design values. At the same time, it is always possible to minimize the costs of seismic protection measures.

The direct dynamic method of calculation for seismic effects according to SBS V.1.1-12: 2014 is applied in individual cases (see Table 6.2 SBS V.1.1-12:2014). And calculations by the spectral method are performed for all designed buildings and structures in seismic regions of Ukraine. Thus, the spectral method of calculating seismic effects is more often used, in comparison with the direct dynamic method of calculating, for territories that, according to the OCP maps, belong to the 6-point zone. In case of discrepancy between the results of the calculation by the spectral and direct dynamic methods, the maximum values of the loads are taken. The spectral method is used worldwide in calculations of the seismic effects of buildings and structures within elastic models.

Table 6.5 is used when applying the spectral method of calculating seismic loads according to SBS V.1.1-12: 2014 [SBS V.1.1-12: 2014] to determine the calculated value of the relative ground acceleration for the investigated site (settlement), depending on the combinations of the calculated seismic intensity on the maps A and B.. This approach is flawed because there is no direct relationship between intensity and peak ground acceleration.

The point is the unit of measurement of seismic intensity. It is quite effective in economic calculations, but unfortunately, there is little information from the engineering and construction point of view [Assessment ..., 1988]. From Appendix D of the document “Scale of seismic intensity” [National ..., 2010] (see Fig. 1) it follows that peak accelerations from 3.5 cm/sec^2 to 500 cm/sec^2 can be observed at 6 points. So, recalculating the points into peak accelerations, according to Table 6. SBS V.1.1-12: 2014, shows that the spectral method for calculating seismic effects does not provide a reliable result.

During the earthquake in Japan on March 11, 2011, various seismic stations recorded peak ground acceleration from 0.3g to almost 3g at approximately the same epicentral distance (about 200 km) [De Luca., Chioccarelli, 2011]. This discrepancy is due to the variety of soil conditions and the features of the propagation of seismic waves in them, that is, the resonant and filtering seismic properties of soils [Kendzera, Semenova, 2016].

An example of the distribution of the seismic effect of the earthquake in Japan on March 11, 2011, and a number of other earthquakes indicates that information on seismic hazards should be provided to designers and operators of seismic structures in physical units of soil oscillations, but not in seismic intensity points. This is required by modern methods of engineering calculations of buildings for an emergency combination of loads, taking into account the seismic effect, which seismologists study and provide designers with information about it.

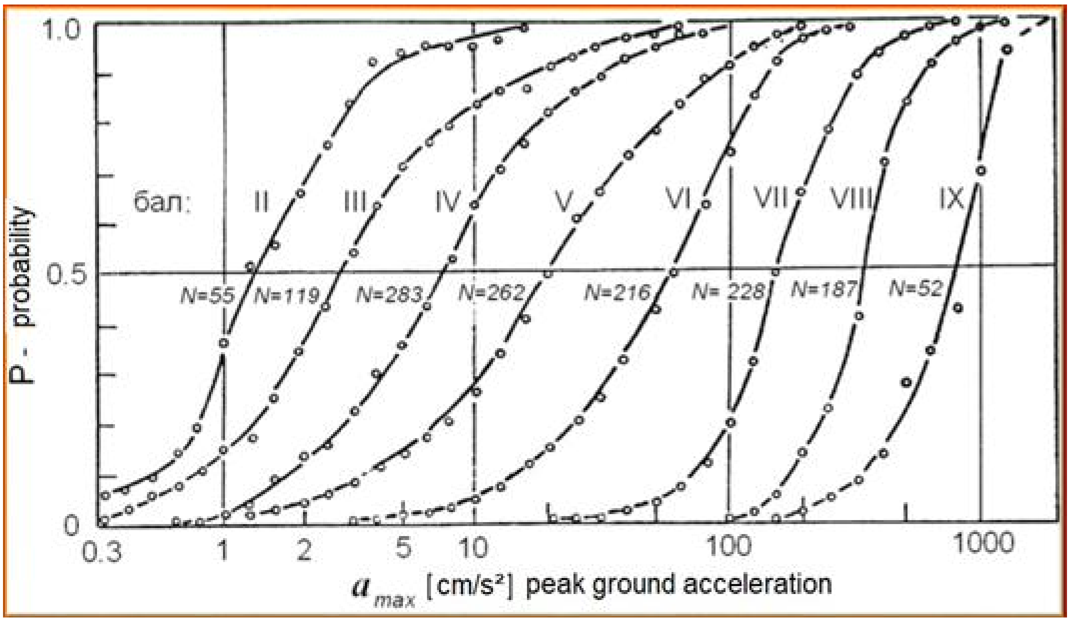


Fig. 1. Relationship (statistical) between the points of macroseismic scale and the acceleration of ground motion during earthquakes (N – number of analyzed earthquakes) per F. F. Apticaev [Apticaev, 2012]

The predicted values of soil oscillations have always been and will be better seismologically substantiated than the used reactions of the "soil base – building" system. The seismic motions of the free surface of the soil layer are more accurately investigated by geophysical methods. Studing the behavior of "soil base – building" systems, designers of earthquake-resistant structures calculate the seismic resistance of the designed object and change the models. They determine the most cost-effective among earthquake-resistant projects. Seismologists provide initial data for modeling the seismic response of buildings and structures during design basis earthquakes.

On May 1, 2019, new changes to DBN V.1.1-12: 2014 came into force. According to these changes, when constructing buildings and structures of the class of responsibility CC2 and CC3 with a height of 73.5, you can use map B instead of map C from Appendix B [DBN B.1.1-12: 2014]. That is, Kyiv, according to the new changes, belongs to the 5-point zone for high-rise construction. So, the spectral method of calculation will be more applicable when designing earthquake-resistant construction, even on soils that were not previously considered as a reliable basis. According to the new changes, the dynamic method of calculating buildings and structures for an emergency combination of loads, taking into account the seismic effect for the specified objects, , will be used only at the request of builders. The spectral method for calculating the emergency combination of loads taking into account the seismic effect does not provide for the use of scoring.In this case, a correct transition from the point to the amplitude parameters of the oscillations of the soil base is required for engineering calculations. Rapid development of high-rise construction in Kyiv, first of all, requires maps of general seismic zoning in physical units of ground motions for the territory of Kyiv. In addition, the seismically most favorable soil conditions have already been built up. These days, high-rise construction is being designed more and more often on alluvial sands, wetlands, etc., that is, on seismically weak soils. Accordingly, buildings on such soils can be severely damaged.

The relevance of the research and the results presented in the article is due to the need to provide the designers of seismic-resistant construction with maps of seismic zoning of settlements and agglomerations in Ukraine in physical units of ground motions: peak ground acceleration (PGA), peak ground velocity PGV or peak ground displacement PGD. The development of seismic zoning maps is caused by the need for modern methods of seismic design and construction [Kendzera, 2015a; Semenova, Kendzera, 2019].

Methodology

The easiest way to build a seismic zoning map in physical units of ground motion is based on the use of instrumental observations. But under conditions of weak seismicity, there is no sufficient amount of instrumental data. Some scientists use correlations or Appendix D of the Seismic Intensity Scale [National ..., 2010] to recalculate the point into physical units of ground motions. The results of this experience are presented in such works as [Aptikaev, 2012; Ulomov, 1999 and others]. Direct recalculations of the normative values of macroseismic intensity into the amplitude parameters of ground motions do not take into account the spectral composition of the seismic effect and the filtering properties of the soil. Therefore, they are incorrect both for using the spectral method of calculating the emergency combination of loads taking into account the seismic effect and for reliable general seismic zoning with a given probability exceeding the values obtained.

The article proposes an analytical-empirical approach for the conditions of Ukraine. This is the only way that can be implemented in conditions of an insufficient number of results of instrumental seismological observations. This approach gives good results in a geologically well-studied area.

Results

Let us illustrate the methodology of mapping the territory of large agglomerations in physical units of soil oscillations on the example of Kyiv.

The first stage of constructing a map of seismic zoning of Kyiv presupposes the use of the method of seismic-geological analogies. It identified relatively homogeneous engineering-geological areas (taxonomic zones) within the city's territory, where the seismic effect may differ significantly. A geological map of Quaternary deposits, pre-Quaternary deposits, a geological map of the crystalline basement, and a scheme of structural-geomorphological zoning were used to identify taxonomic zones (physical zoning). The data were obtained from the catalog of the State Scientific and Production Enterprise “Geoinform of Ukraine” [http://geoinf.kiev.ua/wp/kartograma.htm]. In total, 16 taxonomic zones have been identified within Kiev. For all taxonomic zones, seismic-geological models of the soil were built. A seismic-geological model is a representation of the geological medium in the form of the spatial distribution of physical properties that determine the propagation of elastic oscillations. As a rule, the isotropic medium is modeled. Its seismic properties are determined by the following parameters: velocities of P and S waves, their absorption coefficients, and density. The seismic-geological model consists of geological layers (strata) with different filtering (resonance) properties in relation to seismic waves. The constituent layers can correspond to structural and lithological subdivisions of the geological section of different scales – from thick complexes of rocks to packages of thin facies sedimentary interlayers. Their distinctive features are the limitations in space with rather simple boundaries (bottom and top of the layer) and the difference in the elastic properties of the enclosing strata. In the conditions of sub-horizontal occurrence of the main engineering-geological elements of the soil massif, it is recommended to use one-dimensional models (horizontally layered models of the environment) to assess the effect of sedimentary rocks.

The values of the parameters of the physical and mechanical properties of each layer of the horizontally layered seismic-geological models of all 16 taxonomic zones identified within Kyiv were taken as averages from the reference books [Handbook of Physical ..., 1969; Ladynin, 2010, Goodman, 1980; Lama and Vutukuri, 1978, Physical properties ..., 1984; Dortman, 1984, Dobrynin et al., 2004, etc.]. Additional dynamic properties were determined for each horizontal layer of the seismic-geological model. They take into account the features of the nonlinear inelastic behavior of soils: the dependences of the shear modulus and damping ratio with shear strain amplitude. The data were obtained on the basis of the results of laboratory and field studies of dynamic soil tests, presented in the works [Seed, Idriss, 1970; Roblee, Chiou, 2004; Lanzoet al., 2009; Ishibashi, Zhang, 1993, etc.]. An example of the constructed seismic-geological model of soil profile for taxonomic zone No. 1 is shown in Fig. 2.

It is generally accepted that earthquakes from different seismically active zones are characterized by unique spectral features that differ from other seismic events. To increase the reliability of modeling the calculated seismic influence, it is necessary to perform calculations using the ensembles of accelerograms generated for modeling earthquakes from nearby seismically active zones, and for modeling subcrustal earthquakes from the Vrancea zone. Such earthquakes have a different spectral composition and duration of oscillations in different trains of seismic waves.

To calculate the frequency characteristics of seismic geological models of 16 taxonomic zones identified in the city, 26 input motions were selected in the form of accelerograms recorded on rock deposits with different spectral composition and different durations. The amplitude-frequency composition of oscillations on the free surface for each zoning site was determined by recalculating the input motions from the lower half-space through seismological soil models approximating the geological sections of each zone.

To take into account nonlinear soil deformation, the method of equivalent linear modeling was applied using the ProShake software [ProShake Ground ..., 1998; Schnabel et al., 1972]. As a result, the frequency response of the soil profile was calculated for each seismic-geological model (taxonomic zone). Fig. 3 shows the calculated amplitude-frequency characteristics of seismic-geological models of the soil profiles of 16 taxonomic zones identified within Kyiv.

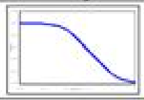
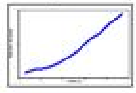
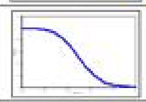
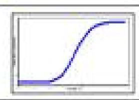
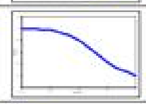
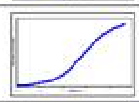
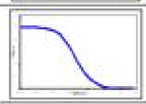
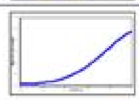
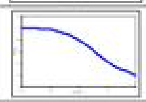
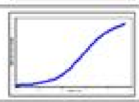
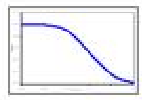
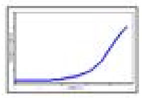
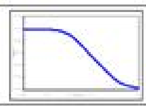
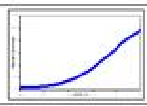
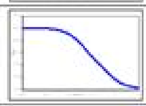
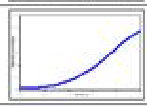
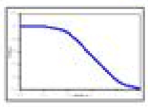
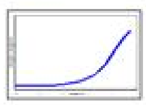
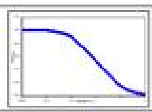
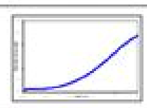
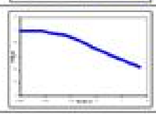
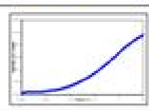
№№ п/п	Lithological composition	Depth (m)	S-wave velocity (Vs), m/sec	Density ρ, g/m³	Parameters of nonlinear properties	
					Variation of shear modulus with shear strain amplitude	Variation of damping ratio with shear strain amplitude
1	Loam forest-like, lake, alluvial	30	250	1,85		
2	Morena, sand	10	280	1,8		
3	Lake loam, alluvial	15	250	1,85		
4	Sand and sandstone	20	340	1,8		
5	Clays are carbonate-free, marls are light gray	25	600	1,92		
6	Sands are greenish-gray, glauconitic-quartz	45	500	1,85		
7	Sands and sandstones, siliceous	15	520	1,95		
8	Clays and siltstones	120	650	1,9		
9	Gray sands with layers of siltstones, carbonaceous clays	10	600	1,95		
10	Motley clays, siltstones, sandstones	35	1300	**2,1**		
11	Diorites		2900	2,7		

Fig. 2. Seismic-geological model of soil profile of taxonomic zone 1

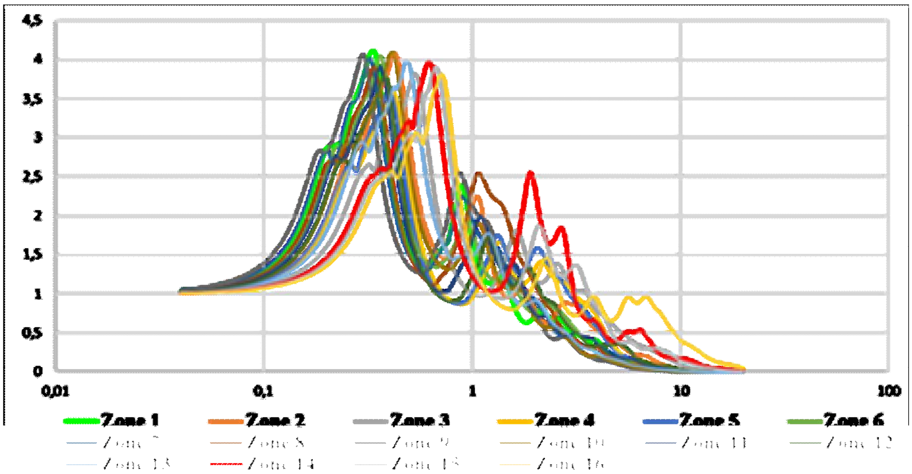


Fig. 3. Frequency characteristics of the soil profiles for 16 taxonomic zones within Kyiv

From the analysis of the calculated frequency characteristics shown in Fig. 3, it is seen that they have similarities: 2 maxima, the first maximum is clear with an amplification of about 4; the second maximum of the frequency characteristics of the soil layer is clear only for some zones (e.g. for zones 8 and 9). The frequency characteristics of the soil profile in zones 13 and 16 show that the second maximum is almost absent for them. Summarizing the description of the frequency characteristics shown in Fig. 3, it can be argued that they have a similar shape, with some offsets of the peak values in frequency.

At the next stage, the averaged amplitude-frequency response was calculated for the ground conditions of the territory of Kyiv. The averaged frequency response was calculated as a function of the distribution of the average values of the spectral amplification of seismic oscillations in all zones in frequency.

For each frequency response, integral spectral amplifications were calculated. In this case, the integral spectral amplification is taken as the area of the subspectral function. The advantage of integral amplification over maximum amplification is that it takes into account the contribution of each frequency to the total variance. To calculate the integral amplification, the Simpson numerical integration method was used in the integration interval from 0 to 20 Hz (engineering frequency range) with an integration step of 0.02 Hz. Simpson's quadrature formula was used at each integration step:

$$\int_{x_0}^{x_2} P_2(x)dx = \int_{0}^{2h} P_2\,(z)dz = \frac{h}{3}(f_0 + 4f_1 + f_2),$$

where h – integration step 0.02 Hz.

At the next step, for each zone, the deviations of the integral amplification from the average value were calculated, that is, from the integral coefficient of the averaged amplitude–frequency characteristic for the soil conditions of the territory of Kyiv. The deviation was calculated as a quotient between the integral amplification of the oscillations of the soils of each zoning site and the averaged integral amplification.

Table 1 shows the values of the deviation of the integral amplification of seismic oscillations from the average value for each taxonomic zone identified within the territory of Kyiv.

Fig. 4 shows the constructed map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value for the territory of Kyiv. The map gives the distribution over the territory of the city of a quantitative assessment of the influence of the spectral characteristics of local soils on the seismic hazard expressed by systemic physical quantities. Table 1 shows that for some taxonomic zones the deviation of the integral amplification from the mean is the same. Thus, on the map of the territory of Kiev in Fig. 4, only 12 zones are highlighted with different values of the deviation of the integral amplification from the average. The constructed map is proposed to be used to apply the spectral method of calculation for an emergency combination of loads taking into account the seismic effect. The map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value can be used to correct the spectra of seismic oscillations falling on the bottom of the sedimentary cover or recalculated to the conditional average soils, for which the calculated accelerograms are formed and the response spectra of unit oscillators with specified natural periods are determined and with damping of oscillations. A map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value for the territory of Kyiv, shown in Fig. 4 is an intermediate step in the construction of Kyiv seismic zoning maps in physical terms of ground motion: peak ground acceleration PGA, peak ground velocity PGV or peak ground displacement PGD. Seismic zoning of the territory of Kyiv in terms of peak ground acceleration will make it possible to more reasonably calculate buildings and structures for seismic effects.

Table 1

Deviation of the integral amplification of seismic oscillations by soils from the average value for 16 taxonomic zones of the territory of Kyiv

Taxonomic zone (Zone)	Deviation of the integral amplification of seismic oscillations from the average value
Zone 1	0,79
Zone 2	1,00
Zone 3	1,27
Zone 4	0,99
Zone 5	0,99
Zone 6	0,76
Zone 7	0,72
Zone 8	0,87
Zone 9	0,72
Zone 10	0,72
Zone 11	0,81
Zone 12	0,87
Zone 13	0,79
Zone 14	1,47
Zone 15	1,40
Zone 16	1,85

Fig. 5 and 6 show the graphs of the PGA change with depth from the bedrock to the free surface in the seismological models of the soil strata of zone 1 and zone 14. The results were obtained by modeling the response of the soil to seismic impact using the ProShake software [ProShake Ground .. ., 1998; Schnabel et al., 1972].

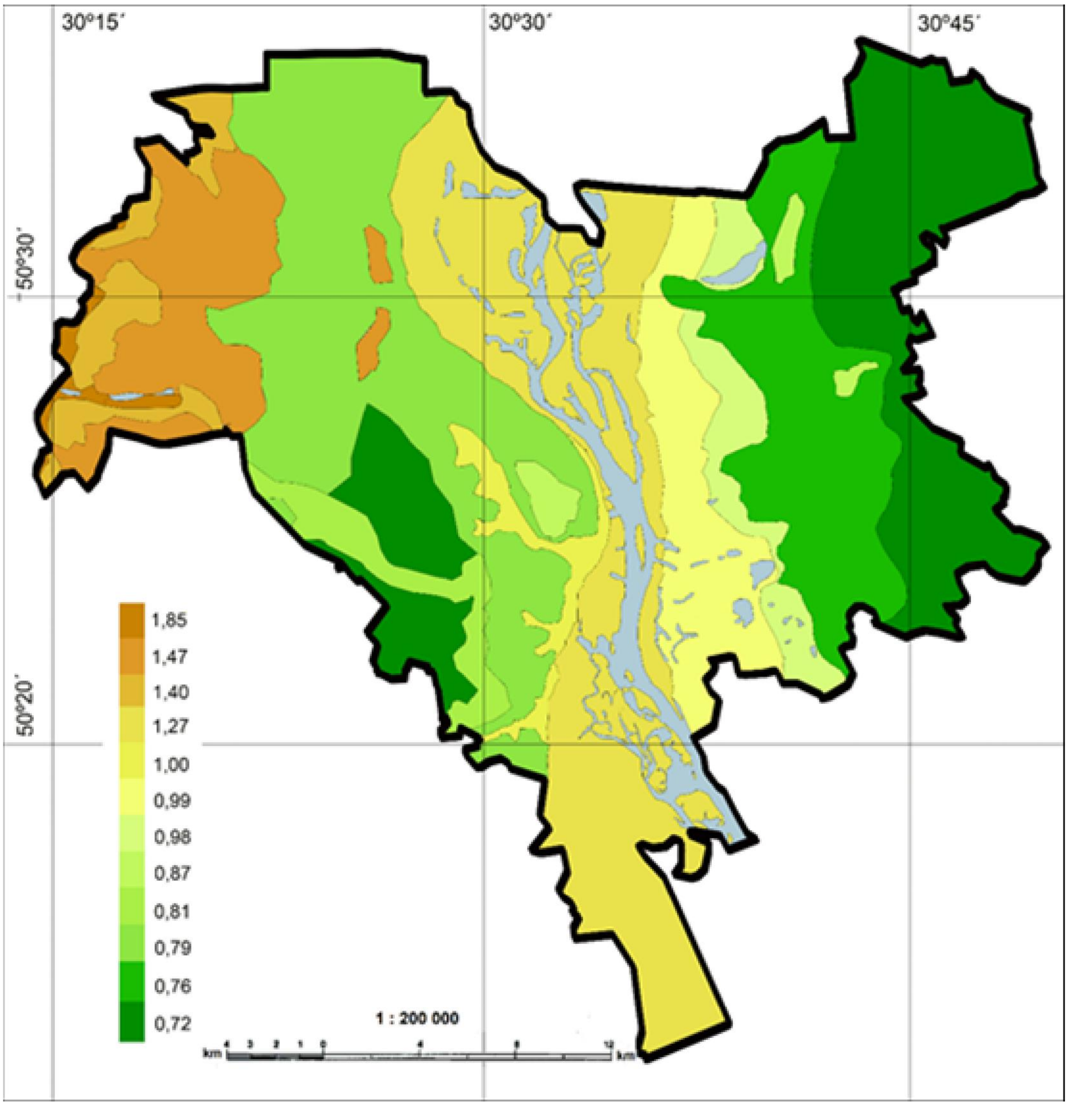


Fig. 4. Map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value for the territory of Kyiv

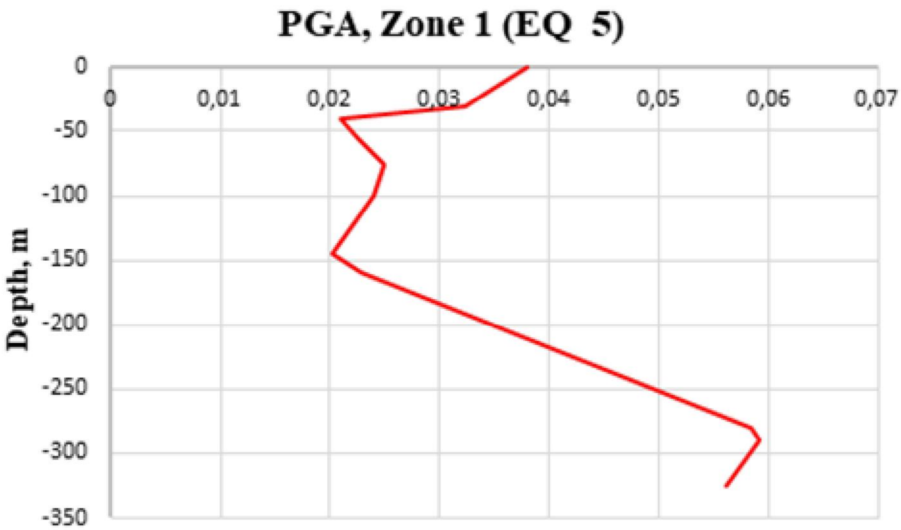


Fig. 5. PGA versus depth curve in the model of the soil of taxonomic zone 1 (zone 1)

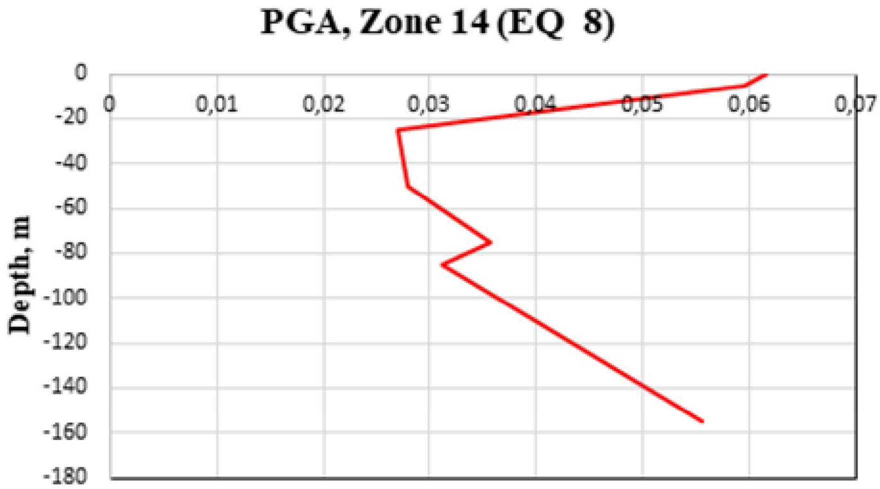


Fig. 6. PGA versus depth curve in the model of the soil of taxonomic zone 14 (zone 14)

Fig. 5 shows that in the seismological soil model of taxonomic zone No. 1, the amplitude of oscillations mainly decreased, although in some layers its slight increase is observed. Overall, from layer 10 to layer 3, the PGA value decreased from 0.06 *g* to 0.022 *g*. In layers 2 and 3, the oscillation amplitude increased from 0.022*g* to 0.038*g*, but not as rapidly as in Fig. 6 in the seismic soil model of taxonomic area No. 14. This phenomenon can be explained by a smoother decrease in acoustic stiffness in the upper layers of the model of taxonomic area No. 1.

From Fig. 6 it is seen that in the model of the taxonomic section №14 the value of PGA from 6 to 3 layer decreases, and in the upper 25 m there is a sharp increase from about 0.025 g to 0.062 g. The increase in PGA is explained by the fact that the upper 25 m of the section of the soil model is composed of loose low-velocity soils. The increase in the amplitude of oscillations of seismic waves in them occurs due to resonance effects. Since, the more luxuriant and loose the soil is, the more likely it is that resonant effects will occur in it.

From the analysis of Fig. 5 and Fig. 6 it follows that a detailed study of the influence of the upper 50-meter layer on the seismic effect on the free surface can lead to both an increase in the amplitude of seismic oscillations (due to resonance phenomena) and a decrease (due to scattering and absorption of energy of elastic waves in soils). The results obtained once again prove that direct recalculations of the normative values of the macroseismic intensity into the amplitude parameters of oscillations do not take into account the spectral composition of the seismic effect and the filtering properties of the soil profile. Therefore, they are incorrect both for using the spectral method of calculating the emergency combination of loads taking into account the seismic effect and for reliable general seismic zoning with a given probability of exceeding the obtained values.

Originality

For the first time , areas (taxonomic zones) have been identified within the territory of Kyiv, where the response of the soil to the seismic effect will differ. For each taxonomic zone, the frequency characteristics of the soil layer were calculated taking into account nonlinear deformation under seismic influences. A map of the distribution of the deviation of the integral amplification of seismic oscillations by soils from the average value for the territory of Kyiv was constructed.

Practical significance

The map of seismic zoning of Kyiv in amplitude terms of soil oscillations is proposed to be used to determine the value of the calculated relative ground accelerations of the construction site under study The spectral method is applied for calculating an emergency combination of loads, taking into account seismic effects.

Conclusions

The article presents the methodology and results of a comprehensive study carried out for seismic zoning) of the territories of settlements or agglomerations in the amplitude parameters of ground oscillations on the example of the territory of Kyiv. An analytical-empirical approach is used since this is the only available method that can be implemented in conditions of an insufficient number of results of instrumental seismological observations. Within the territory of Kyiv, using the method of seismic-geological analogies, areas (taxonomic zones) were identified, where the seismic effect may differ significantly. For each taxonomic zone, a computational seismic-geological model with inelastic deformation parameters has been built. It allows taking into account the occurrence of nonlinear effects under significant seismic influences. Equivalent linear modeling was used to calculate the frequency characteristics of seismic-geological soil models for each taxonomic zone. The averaged amplitude-frequency response was calculated for the ground conditions of the territory of Kyiv. A map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value for the territory of Kyiv was constructed. The integral spectral amplification is the area of the subspectral function. The advantage of integral amplification over maximum amplification is that it takes into consideration the contribution of each frequency to the total variance. The map takes into account the models of attenuation of seismic oscillation in soils. The constructed map is proposed to be used in the spectral method of calculating buildings and structures for an emergency combination of loads, taking into account the seismic impact since the conversion of the seismic intensity scale (MSK-64) into the amplitude of ground oscillations is incorrect. The map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value can be used to correct the spectra of seismic oscillations falling on the bottom of the sedimentary cover or recalculated to the conditional average soils. The calculated accelerograms are formed for them and the response spectra of single oscillators with specified natural periods are determined with damping of oscillations. The map of the distribution of the deviation of the integral amplification of seismic oscillations from the average value for the territory of Kyiv, presented in the article, is an intermediate stage in the construction of seismic zoning maps for Kyiv in physical terms of ground oscillations: peak ground accelerations PGA, peak ground velocities PGV or peak ground displacements PGD. Seismic zoning of the territory of Kyiv in terms of peak ground acceleration will make it possible to more reasonably calculate buildings and structures for seismic effects.

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СЕЙСМІЧНЕ ЗОНУВАННЯ КИЄВА В ФІЗИЧНИХ ПАРАМЕТРАХ КОЛИВАНЬ ҐРУНТУ

Мета. У роботі обґрунтовано необхідність побудови карт сейсмічного зонування Києва в фізичних термінах коливань ґрунту: пікових прискореннях (PGA), пікових швидкостях (PGV) або пікових зміщеннях (PGD), які є основою для ефективного використання методів розрахунку сейсмічних навантажень на будинки, споруди та окремі відповідальні конструкції. Проміжним етапом створення таких карт є розроблення карти сейсмічного зонування (районування) території Києва в термінах відносних інтегральних оцінок спектральних приростів у сейсмічних коливаннях ґрунту, які виникають за рахунок впливу особливостей розподілу фізичних параметрів ґрунтових комплексів. Проміжна карта дає розподіл на території міста кількісної оцінки впливу спектральних характеристик ґрунтових комплексів на сейсмічну небезпеку, виражену системними фізичними величинами. **Методика.** Застосовано аналітично-емпіричний підхід до картування сейсмічної небезпеки територій. У межах території Києва методом сейсмогеологічних аналогій виділено ділянки (таксонометричні зони), на яких сейсмічний ефект може суттєво відрізнятися як за фізичними параметрами: зміщення, швидкість, прискорення, так і за здатністю ґрунтових товщ істотно впливати на спектральні характеристики ґрунтових комплексів. Для кожної таксонометричної зони побудовано розрахункову сейсмогеологічну модель із параметрами непружного деформування, які дають змогу врахувати виникнення нелінійних ефектів у разі значних сейсмічних впливів. Методом еквівалентного лінійного моделювання розраховано частотні характеристики ґрунтових моделей кожної таксонометричної зони. Розраховано усереднену амплітудно-частотну характеристику для ґрунтових умов території Києва. Побудовано карту розподілу відхилення інтегрального коефіцієнта підсилення ґрунтами сейсмічних коливань від середнього значення для території Києва. Інтегральним коефіцієнтом спектрального підсилення прийнято площу підспектральної функції. Виконано динамічний аналіз поширення сейсмічних коливань у сейсмоґеологічних моделях та проілюстровано вплив верхнього осадового шару на значення пікових прискорень ґрунту PGA на вільній поверхні. **Наукова новизна.** Вперше в межах території Києва виділено ділянки (таксонометричні зони), на яких відрізнятиметься реакція ґрунтової товщі на сейсмічний вплив. Побудовано карту розподілу відхилення інтегрального коефіцієнта підсилення ґрунтами сейсмічних коливань від середнього значення для території Києва. **Практична значущість.** Карту сейсмічного зонування (районування) Києва в амплітудних термінах коливань ґрунту запропоновано використовувати у разі застосування спектрального методу розрахунку на аварійне сполучення навантажень з урахуванням сейсмічного впливу для визначення значення розрахункових відносних прискорень ґрунту досліджуваного будівельного майданчика.

Ключові слова: сейсмічне зонування; сейсмічна небезпека, пікові прискорення ґрунту; сейсмостійке будівництво.

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