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Research Paper

Prediction of the influence of near-surface soils on seismic surface oscillations on the example of sites of the territory of Ukraine

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ABSTRACT: *The article discusses methods for modeling the frequency response of local soil conditions to seismic effects. Comparison and analysis frequency response of soil of the territory Central Sports Club of the Armed Forces of Ukraine in Kyiv obtained taking into account the nonlinear deformation of the soil and without taking into account under seismic load are presented. The paper considers and analyzes the results of a study of the influence of the sedimentary layer on seismic oscillations on the surface using the example of the territory of the Yagotin compressor station (Ukraine). The presence of frequency responses, which most accurately (at the level of modern knowledge) reflect the influence of the soil under the future development, can reduce its cost and at the same time increase seismic resistance due to the development of design solutions that exclude the coincidence of the natural frequencies of the projected building with the maxima of the frequency response of the soil.*

KEYWORDS: *Frequency Responses, Natural Frequencies, Earthquakes, Seismic Risk*

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I. INTRODUCTION

The main issue in the prediction of the earthquake's aftermath is what will happen with the concrete object exposed to a maximal earthquake that can occur with the given no exceedance probability over a conventional period, which as a rule is taken as 50 years. Prediction of the effects of future earthquakes is an important problem, the reliable practical solution of which is possible, when only the knowledge geological, geophysics, hydrogeological, seismological, geotechnical and seismic design engineers and builders were being combined.

The increasing pace and volume of construction of high-rise buildings and important engineering structures require the development of new territories, which, according to expert estimates, are often characterized by complex engineering and geological conditions and deteriorated seismic properties.

It should be noted that even under favorable seismic conditions of the site, the seismic safety of buildings or structures built on it is not guaranteed, since in some cases resonance effects can occur in soils (a significant increase in oscillations at specific frequencies).

The probabilistic assessment of relative loss in an object cost caused by destruction or loss of functional capacity is called the seismic risk. As is clear from Figure 1, the seismic risk consists of probabilistic assessment of seismic hazard and seismic vulnerability of an object.

Figure 1: Components of seismic risk

The seismic hazard is a probabilistic assessment of the formation of maximal seismic impacts (oscillations) caused by earthquakes from the possible initiation zones, which are hazardous for the specified site. This estimate is expressed in points of macroseismic scale, or time acceleration series. It is the most fully described using design accelerograms.

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The seismic vulnerability of an object defines its resistance to seismic effects of various values, including effects conditioned by the seismic hazard of its location area. The quantitative estimate of seismic vulnerability is probabilistic and is determined for buildings and structures in the design stage using theoretical calculations or the physical modeling. The seismic vulnerability of existing objects is most reliably determined through experimental engineering seismometric observations. Ideally, the vulnerability should be represented as probabilistic curves, on which the relative degree of damage (loss of functional capability) depends on various characteristics of seismic hazard.

The seismic hazard is an objective characteristic of the locality of the area. It depends on the natural environment of the locality: seismicity of the territory, distance to focus zones, parameters of maximal earthquakes that can occur in those areas, their recurrence in time, local soil conditions, relief, presence of ruptured tectonic structures, the spectral distribution of oscillations and other factors.

The task of seismic micro-zoning is to assess the impact of local engineering and geological conditions of the construction site on the intensity, shape and range of oscillations of the soil surface during strong earthquakes. These parameters determine the nature of the destruction of buildings in different soil conditions.

For seismic design, it is necessary to know not only the magnitude of the oscillation intensity and the values of the maximum peak accelerations but also information on how seismic effects are distributed in frequency. It is known that the soil mass under the construction site behaves like a filter: at some frequencies, the soil mass transmits oscillations almost unchanged, while at others it either amplifies or absorbs them. When designing earthquake-resistant buildings and structures, it is important not to allow the maxima of the frequency response of the soil to coincide with the natural frequencies of buildings and structures.

The frequencies corresponding to the resonant amplification can be determined from the amplitude-frequency characteristics of the soil strata. In this case, it is desirable to consider a wide frequency range from 0.05 to 20 Hz. This range is of the greatest interest in seismic zoning since it contains the vibration frequencies of the main types of buildings, structures and their critical structures, as well as the maximums of the vibration spectra during strong earthquakes.

The frequency response of the soil under the construction site can be obtained instrumentally, based on records of oscillations of weak earthquakes and microseisms. Registration of fluctuations in weak earthquakes is not always possible in areas with low seismicity and gives not very accurate results through industrial noise. With this in mind, seismic observations at a construction site are usually limited to recording microseisms. In the formation of the field of microseismic oscillations, as a rule, numerous natural and anthropogenic sources are involved, the contribution of which is difficult to account for. Due to significant errors, the method of recording high-frequency microseisms gives only approximate values of the frequency characteristics of soils. As a rule, this method is used only to assess the increase in seismic intensity in points of the macroseismic scale.

Calculation methods are an alternative to instrumental methods.

It should be noted that computational methods provide sufficiently accurate results only in the presence of reliable geotechnical and seismological data on the structure of the soil strata of the construction site, as well as on the lithology of geological layers and the physical and mechanical properties of the constituent materials. Based on these data, models of the soil strata under the construction site are constructed (with arbitrary interfaces or horizontally layered vertically heterogeneous models), which serve as input data when using calculation methods for determining its frequency characteristics.

Obtaining data for building horizontally layered models of the environment is much easier and more realistic. The fields calculated in such models are stable to errors in the initial data. In this regard, the use of just such models is assumed by SBS V.1.1-12: 2014 [2] and Eurocode 8. For calculating the frequency characteristics of horizontally layered models of the geological environment, the Thompson-Haskell matrix method is used [5].

II. METHODS FOR DETERMINING THE FREQUENCY RESPONSE OF SOIL

The frequency response of the soil under the construction site can be obtained instrumentally, based on records of oscillations of weak earthquakes and microseisms. Registration of fluctuations in weak earthquakes is not always possible in areas with low seismicity and gives not very accurate results through industrial noise. With this in mind, seismic observations at a construction site are usually limited to recording microseisms. In the formation of the field of microseismic oscillations, as a rule, numerous natural and anthropogenic sources are involved, the contribution of which is difficult to account for. Due to significant errors, the method of recording high-frequency microseisms gives only approximate values of the frequency characteristics of soils. As a rule, this method is used only to assess the increase in seismic intensity in points of the macroseismic scale.

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A linear or nonlinear approach can be used to model the response of the soil layer to seismic impacts. Linear - is described by a linear-elastic model of the reaction of the soil layer. It is assumed that at dynamic loads the processes in soils will correspond to the linear stress-strain dependence. But under intense seismic effects in soils, phenomena arise that cannot be described by the linear theory of elasticity. In intense earthquakes, the proportionality between stresses and strains is disturbed, the phenomenon of saturation occurs, this is when the stresses grow more slowly than in smaller values of strains. The value of stresses at which the proportionality of the dependence between stresses and strains disappears is the threshold of elasticity. The threshold of elasticity for different categories of soils is different [1] and is determined, first of all, by the absorbing properties [11]. Therefore, for the analysis of the reaction of the soil to seismic impacts, considerable attention has recently been paid to nonlinear approaches [3, 4, 7].

The mechanisms of linear transformations of seismic waves in the near-surface soil strata, which lead to increased oscillations, are well studied. Unlike nonlinear mechanisms, they are fully taken into account in the practice of seismic microzoning. Since seismic microzoning is usually carried out for areas that can be exposed to strong earthquakes, adequate consideration of the nonlinear response of the soil is necessary [8]. Soil response can be considered linear under weak seismic impacts. At high impacts, the contribution of nonlinearity will depend on the magnitude of seismic deformations [7].

The nonlinearity of the response of the near-surface soil strata leads both to a change in the spectral composition of seismic oscillations, sometimes very significantly, and to a change in the amplification of seismic oscillations. At a sufficiently high intensity of oscillations, nonlinear absorption mechanisms begin to operate, which lead to a weakening of oscillations at high frequencies, but do not attenuate low-frequency oscillations. Changes in the spectral composition of oscillations on the surface associated with the nonlinearity of the soil response are manifested in the shift of resonance frequencies to the low-frequency region. The amplification of seismic oscillations on the surface is reduced due to the nonlinearity of the response of the soil compared to the linear response in dry soils (when groundwater is deposited at a depth of 10 m or more). In water-saturated soils (when the groundwater level is at a depth of less than 10 m), such an increase is less noticeable. These conclusions were made both on the basis of the analysis of real records of strong earthquakes and the results of numerical simulation [8].

In equivalent linear modeling, the soil is considered as a linear viscoelastic material, and its nonlinear properties are taken into account by introducing the dependences of the shear modulus and damping ratio with shear strain amplitude. Such dependencies are selected for each layer of the soil model separately according to the data on the lithological composition and depth of occurrence, obtained on the basis of the results of laboratory or field studies. For example, according to the data of [6, 10].

Figure 2 shows the amplitude-frequency characteristic of the soil under the construction site of the stadium of the Central Sports Club of the Armed Forces of Ukraine in Kyiv, obtained by a) linear modeling, c) equivalent linear modeling using the ProShake software package [9].

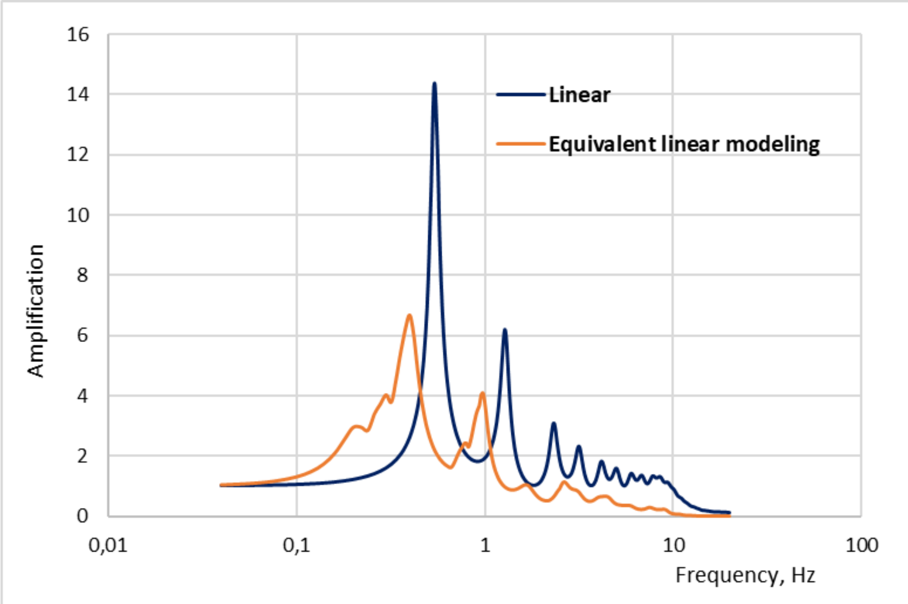

Figure 2: Frequency characteristics of the soil under the construction site of the stadium of the Central Sports Club of the Armed Forces of Ukraine in Kyiv, obtained by a) linear modeling, c) equivalent linear modeling

Fig. 2 that the frequency response calculated by linear modeling (when the absorption decrement is considered constant for each layer) differs from the frequency response calculated using the equivalent linear modeling (which takes into account that the absorption coefficient and shear modulus depend on the level of deformation).

In linear modeling of the response of the soil to seismic influences, only the amplitude transformation of the frequency components of the output spectrum occurs, while in equivalent linear modeling, as can be seen from Fig. 2, the absolute maxima shift towards lower frequencies. Experience has shown that the use of linear modeling can lead to the appearance of false resonance peaks in the frequency response of the soil mass. The similarity between the results of equivalent linear and nonlinear simulations depends on the degree of soil nonlinearity. Both methods give good results in the real estimation of soil response at small deformations, and at very large deformations, nonlinear modeling gives results closer to those established empirically.

The obvious conclusion is that by choosing the wrong approach to modeling the response of the soil to seismic effects from earthquakes, it is possible to obtain false values of the resonance frequencies of the soil mass, which during an earthquake can lead to the destruction of a building due to resonance effects not taken into account in the design.

III. AMPLIFICATION SITE EFFECTS OF THE YAGOTIN COMPRESSOR STATION (UKRAINE)

The site of the Yagotin compressor station is characterized by a flat relief and is located in the left-bank part of the Dnieper River valley. In engineering-geological terms, the studied area is located within the Dnieper-Donets depression.

The upper part of the geological section is represented by deposits of aeolian and glacial genesis. Mostly these are loess loams, overlain by moraine loams. Groundwater lies at a depth of 7-12 m. The thickness of the sedimentary layer to bedrock is almost 900m.

During seismic microzoning within the site of the Yagotin compressor station one zone of seismic effect was identified. Accordingly, one seismic-geological model was built. One frequency characteristic of this model was calculated.

Figure 3 shows a velocity model of a section of soil to bedrock under the study site. It can be seen from Fig. 3 that the velocity model is characterized by rather a low shear wave velocity values. Especially low values up to 500 m/s in the upper 50-meter layer.

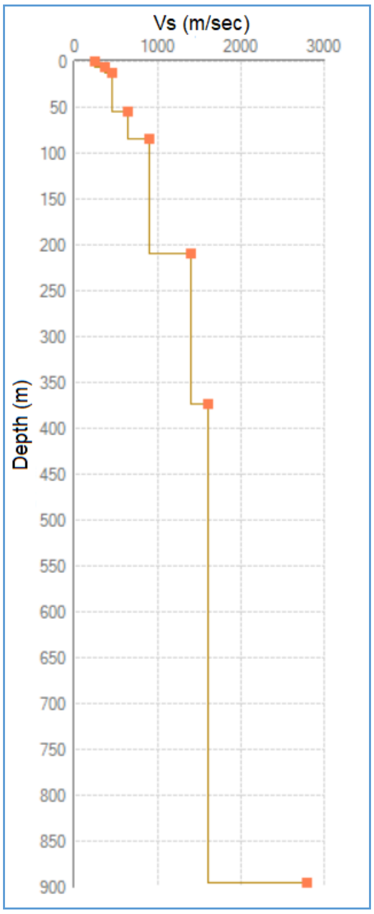

Figure 3: The velocity model of a section of soil to bedrock under the site of the Yagotin compressor station

Equivalent linear model was used in the calculations. Equivalent linear site response analyses were performed using Proshake software [9]. The behavior of each layer was specified by the Kelvin-Voigt model (viscoelastic). The nonlinearity of soil stress-strain behavior means that the shear modulus of the soil is constantly changing. For each layer, the shear modulus reduction and damping ratio curves were chosen in order to take into account the nonlinearity.

In Figure 4 shows the amplitude-frequency response of the soil stratum model under the site of the Yagotin compressor station

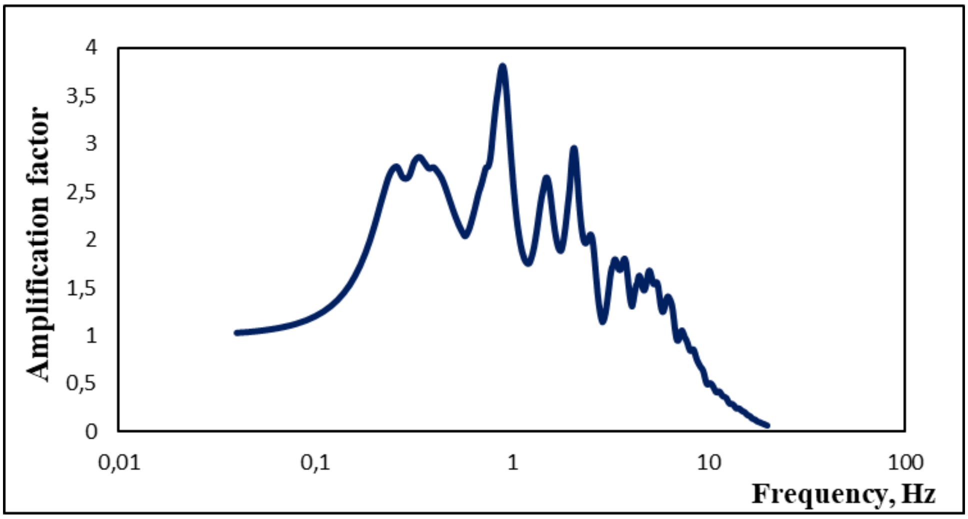

Figure 4: Frequency response of the soil under the site of the Yagotin compressor station

An analysis of the frequency response shown in Figure 4 showed that seismic oscillations can be amplified by the soil under the studied area in the range 0.18-2.66 Hz. The maximum amplification coefficient is 3.8 at a frequency of 0.9 Hz. The frequency response has a wide range of resonant amplification of seismic oscillations by soils. The highest amplifications are observed in the low-frequency range. This is due to the large thickness of the sedimentary layer of about 900m.

Taking into account the amplification of seismic oscillations in the low-frequency range is necessary for earthquake-resistant design of high-rise and extended structures since they are characterized by low natural frequencies of oscillations. Such objects located on the territory of Ukraine may suffer damage under the influence of strong subcrustal earthquakes from the Vrancea zone. Seismic effects from these earthquakes are characterized by low-frequency long-period oscillations and propagate over long distances without significant attenuation, which can lead to dangerous resonant effects.

The frequency response most fully reflects the influence of the soil on the transformation of the input motion from the bedrock. Information about the seismic site effects allows increasing the seismic resistance of structures by developing design solutions that prevent the natural frequencies of the designed building from coinciding with the maxima of the frequency characteristic of the soil

IV. CONCLUSION

The destructions and damages of earthquake-resistant structures during earthquakes are associated not only with poor construction quality and unfavorable ground conditions of their sites but also with the coincidence of the natural frequencies of structures with their own frequencies of the frequency response of the soil strata (resonant effects); liquefaction of soils or partial loss of their bearing capacity (nonlinear effects).

The methods of determining the frequency of oscillations of the near-surface soil during an earthquake are considered. Comparison and analysis frequency response of soil of the territory Central Sports Club of the Armed Forces of Ukraine in Kyiv obtained by different modeling methods are presented. The paper considers and analyzes the results of a study of the influence of the sedimentary layer on seismic oscillations on the surface using the example of the territory of the Yagotin compressor station (Ukraine).

The presence of frequency responses, which most accurately (at the level of modern knowledge) reflect the influence of the soil under the future development, can reduce its cost and at the same time increase seismic resistance due to the development of design solutions that exclude the coincidence of the natural frequencies of the projected building with the maxima of the frequency response of the soil.

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