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ANALYSIS OF THE INFLUENCE OF DIFFERENT SOIL TYPES ON THE NATURAL FREQUENCIES OF MULTI-STOREY REINFORCED CONCRETE BUILDINGS

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According to current concepts, the construction of multi-storey and high-rise buildings is quite topical. Increasing the number of storeys and building density provokes an increase in loads and forces on the structural elements of the building, as well as on the soil base. It is necessary to take into account the mechanical characteristics of the soils underlying multi-storey buildings to improve the design models of objects when determining the forces and deformations in their elements. A vital indicator in monitoring the structural characteristics of buildings is global stiffness. Natural frequencies determined by modal analysis are used to detect its change. The purpose of this study is a numerical analysis of the effect of changes in the parameters of the soil base on the natural frequencies and values of vibrations of multi-storey reinforced concrete frame buildings using software systems. In this study, four variants of design models with rigidly fixed foundations and elastic foundations with different types of soils were developed. In the models with elastic foundations, stable soils were used, such as sandy, moderately stable, represented by loams and sandy loams, and weak soils containing a layer of peat. The building scheme was developed using the SCAD software package with the application of the finite element method. Taking into account that 90% of the territory of Ukraine is located in complex engineering and geological conditions, the use of the finite element method allows to effectively solve complex problems of interaction of heterogeneous elements, including in a nonlinear approach. As a result, it was found that the type of soil foundation affects the change in the natural vibration frequencies of a building. In the model with a rigidly fixed foundation, the frequencies are the highest, and the eigenvalues of oscillations are the lowest. A point that should be mentioned is that in the variants with an elastic foundation, the lowest frequencies are observed in the model on weak soils, and the highest values are typical for sandy foundation soils.

Keywords: multi-storey reinforced concrete buildings, soil base, finite element method, numerical modeling, modal analysis, natural frequencies.

Introduction. According to current trends, the construction of multi-storey and high-rise buildings is quite topical. In accordance with this statement, the density of buildings, the level of transportation networks and the volume of underground construction are increasing. This provokes an increasing of loads and forces on the structural elements of the building, as well as on the ground. At the same time, the development of deformations in the building's foundation can become critical or even lead to structural failure.

To increase the accuracy of the calculation of the stress-strain state of a building, it is important to take into account the reactions of the foundation that affect the redistribution of forces in the load-bearing structures. For this purpose, it is necessary to consider the characteristics of soils at the base of multi-storey buildings to improve the calculation of object models when determining forces and deformations in their elements [1].

An important indicator in monitoring the structural characteristics of buildings and the state of structures is global stiffness. Natural frequencies are most often used to determine its change [2]. This parameter is determined by the operational modal analysis from the influence of environmental factors [3, 4].

Studies [3, 5] emphasize that one of the most important factors of influence is the interaction of soil with the building. The works pay attention to the interaction of low- and medium-rise buildings with the wall structural system and the foundation. The authors have found that the greatest dynamic effects are observed for the cases of bases consisting of weak soils. In such cases, the natural frequencies of the building are reduced compared to the model with a rigidly fixed foundation. Buildings with a wall structural system are the basis of the old housing fund. Currently, the construction industry is designing buildings with a frame structural system. Thus, it is important to conduct research on soil-building interaction at the design stage of modern frame buildings. The effect of the interaction between the soil base and the building allows for a more complete consideration of the indicators of influence on the safety of the structure [6]. Therefore, such studies are very topical.

The purpose of this study is to assess the influence of soil foundation parameters on the natural frequencies and values of vibrations of multi-storey reinforced concrete frame buildings using software packages.

Data for numerical modeling. The building model is a full framed. The spatial stiffness is provided by rigidly attached girders to columns and two stiffening cores. The foundation of the building is slab. The building's dimensions in plan are 18×58 m, with a floor height of 4.2 m. The building has 5 floors and 1 ground floor. The city of Dnipro (Ukraine) is taken as the construction area.

Four variants of calculation models were developed for this study. The first model variant assumes a rigidly fixed foundation, and all other variants assume an elastic foundation. In variants 2-4, three soil types are used, which differ in their composition and strength of soil layers [5]. Thus, the second variant presents the most stable soil, the third - moderately stable, and the fourth - weak.

The building scheme was developed using the SCAD software package with the application of the finite element method. This method is the main one in the field of structural mechanics for calculating building structures [7]. The building's finite element type is quadrilateral, the number of design elements is 64345, and the number of nodes is 51671. Rigid inserts were used to ensure the correctness of the building model and calculation. A general view of the design scheme is shown in Fig. 1.

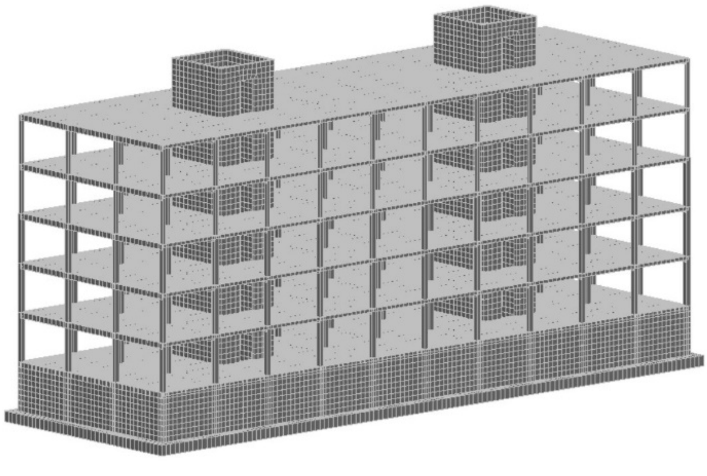

Fig. 1. Design scheme of the building using the finite element method

Different soil types were used to analyze 2-4 model variants. The soil bases were created using the Cross program and then used in the SCAD program. The Cross program is required to determine changes in the bedding coefficient under the foundation slab. This is done based on geological survey data, the building area, including its dimensions, well positions and characteristics.

The size of the predominant grain fraction, the content of dusty clay particles, the rolling of the grains and the presence of surface films on them are important for the dynamic stability of the bases [8]. The dynamic stability of soils is also affected by their compatibility [9]. For sands, its increase provokes a decrease in dynamic stability.

The parameters of the soil layers were selected based on research data [5]. In the second variant of the scheme, the soils are sandy and are considered the most stable (Table 1). In the third variant, the soil base is moderately stable and is represented by loams and sandy loams (Table 2). In the fourth version of the model, the third type of soil base is presented, which is weak and has a peat layer (Table 3).

Table 1

Characteristics of the soil type 1 [5]

Soil Description	Specific Weight		Modulus of Elasticity, MN/m²	Poisson's Ratio ν	Thickness, m	Ordinate from Ground Level, m
	γ, kN/m³	γ_{sat}, kN/m³				
Sand, closelygraded	17.0	19.0	30.0	0.30	0.80	0.80
Sand	19.0	21.0	30.0	0.30	2.50	3.30
Dusty sand	18.0	20.3	18.0	0.30	3.50	6.80
Sand, gravelly sand	18.0	20.0	20.0	0.30	7.20	14.0

Table 2

Characteristics of the soil type 2 [5]

Soil Description	Specific Weight		Modulus of Elasticity, MN/m²	Poisson's Ratio ν	Thickness, m	Ordinate from Ground Level, m
	γ, kN/m³	γ_{sat}, kN/m³				
Sand, closely graded	17.0	19.0	30.0	0.30	0.80	0.80
Sand	19.0	21.0	30.0	0.30	2.50	3.30
Clay, low plasticity	19.0	19.5	2.50	0.42	3.50	6.80
Sand-clay mixture	18.0	19.0	10.0	0.35	7.20	14.0

Table 3

Characteristics of the soil type 3 [5]

Soil Description	Specific Weight		Modulus of Elasticity, MN/m²	Poisson's Ratio ν	Thickness, m	Ordinate from Ground Level, m
	γ, kN/m³	γ_{sat}, kN/m³				
Sand, closely graded	17.0	19.0	30.0	0.30	0.80	0.80
Sand	19.0	21.0	30.0	0.30	2.50	3.30
Peat	10.40	10.40	1.0	0.40	0.30	3.60
Dusty sand	18.0	20.3	18.0	0.30	3.20	6.80
Sand, gravelly sand	18.0	20.0	20.0	0.30	7.20	14.0

The elements of a frame building are affected by various types of loads. Loads differ in their origin, nature, place of application, change in space, time and intensity of impact, and other parameters. Thus, for a more accurate calculation of building structures, it is necessary to take into account the correct design combinations of various impacts. In the full calculation of the models, constant, long-term and short-term loads were considered [10].

The modal analysis of 10 forms of natural vibrations of each of the scheme variants was also performed. The number of forms was determined based on the percentage of collected effective modal masses in accordance with the requirements of DBN B.1.1-12:2006 [11].

The multifrontal method in the SCAD software package was used to calculate buildings. This method is based on Gaussian exclusion and involves the parallel arrangement and elimination of already collected equations. Thus, element by element is added to the stiffness matrix of the system instead of its complete collection in an explicit form. The equations are ordered using heuristic algorithms, which involves the creation of several fronts [12].

Analysis of results. As a result of calculating the modal analysis of the building, the natural frequencies and values of oscillations for 10 modes were obtained. Consequently, graphs of eigenvalues and frequencies of natural modes were drawn for each of the model variants (Figs. 2, 3).

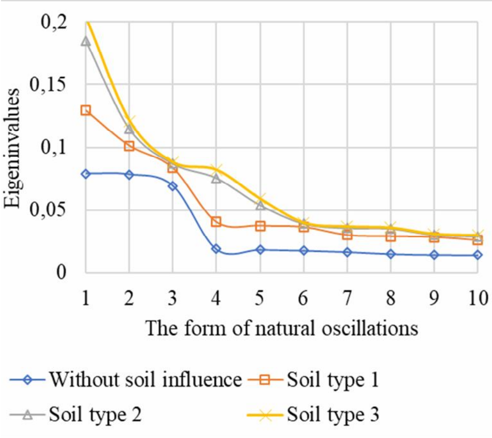

Fig. 2. Graph of eigenvalues of natural oscillation forms

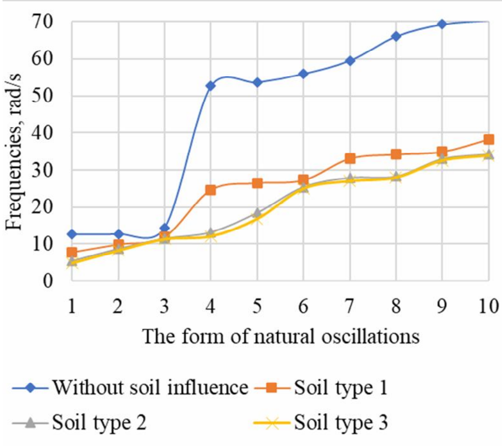

Fig. 3. Graph of frequencies of natural oscillation forms

The eigenvalues of the oscillation forms increase with decreasing stability of the soil base, as shown in Figure 2.In the case of a rigidly fixed foundation, the eigenvalues are the lowest compared to those of an elastic foundation. Meanwhile, Figure 3 shows that the values of the frequencies decrease with decreasing soil stability. In the case of a fixed foundation, the frequencies are the highest in all modes. Comparing the frequencies in the variants with an elastic base, it is possible to distinguish higher values in soil type 1, which is represented by sandy soils. Accordingly, the lowest frequencies are typical for the last model variant with soil type 3.

Based on the graphs, there is an obvious increase in the frequency values between the third and fourth modes. This is due to a change in the form of movement between the modes. In the first and second forms, the motion is translational, and in the third, it is torsional. Such a strong difference in the values in the fourth mode is explained by the torsional multidirectional movement of the building.

Conclusion. From the results obtained from this study, it can be concluded that the soil base affects the change in the natural frequencies of the building. The effect of soil-building interaction is an important factor in the modal analysis of a building. In the model with a rigidly fixed foundation, the frequencies are the highest and the natural vibration values are the lowest. It should also be noted that in the variants with an elastic foundation, the lowest frequencies are observed in the model on weak soils (soil type 3), and the highest - on sandy soils (soil type 1).

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АНАЛІЗ ВПЛИВУ РІЗНИХ ТИПІВ ҐРУНТІВ НА ВЛАСНІ ЧАСТОТИ БАГАТОПОВЕРХОВИХ ЗАЛІЗОБЕТОННИХ БУДІВЕЛЬ

За сучасними тенденціями будівництво багатоповерхових та висотних будівель є доволі актуальним. Збільшення поверховості та щільності забудови провокує збільшення навантажень та зусиль на конструктивні елементи будівлі, а також на ґрунтову основу. Є необхідним урахування механічних характеристик ґрунтів, що лежать в основі багатоповерхових будівель для вдосконалення розрахункових моделей об'єктів при визначенні зусиль і деформацій в їхніх елементах. Важливим показником у моніторингу структурних характеристик будівель є глобальна жорсткість. Для визначення її зміни використовуються власні частоти, що визначаються за допомогою модального аналізу. Метою даного дослідження є чисельний аналіз впливу зміни параметрів ґрунтової основи на власні частоти та значення коливань багатоповерхових залізобетонних каркасних будівель з використанням програмних комплексів. У даному дослідженні розроблено чотири варіанти розрахункових моделей з жорстко закріпленою основою та пружними основами із різними типами ґрунтів. У моделях з пружною основою застосовано 3 типи ґрунтових основ: стійкі ґрунти, а саме піщані, помірно стійкі, що представлені суглинками та супіском, та слабкі ґрунти, що містять у своєму складі шар торфу. Схему будівлі розроблено за допомогою програмного комплексу SCAD із застосуванням методу скінченних елементів. Враховуючи, що 90 % території України розміщено у складних інженерно-геологічних умовах, застосування методу кінцевих елементів дозволяє ефективно розв'язувати складні задачі взаємодії різнорідних елементів у тому числі і в нелінійному підході. У результаті встановлено, що тип ґрунтової основи впливає на зміну власних частот коливань будівлі. У моделі із жорстко закріпленим фундаментом частоти є найвищими, а власні значення коливань найнижчими. Також слід зазначити, що у варіантах з пружною основою найнижчі частоти спостерігаються у моделі на слабких ґрунтах, а найвищі значення характерні для піщаних ґрунтів основ.

Ключові слова: багатоповерхові залізобетонні будівлі, ґрунтова основа, метод скінченних елементів, чисельне моделювання, модальний аналіз, власні частоти.

Kovrova V.O., Volkova V.E.

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According to current concepts, the construction of multi-storey and high-rise buildings is quite topical. Increasing the number of storeys and building density provokes an increase in loads and forces on the structural elements of the building, as well as on the soil base. It is necessary to take into account the mechanical characteristics of the soils underlying multi-storey buildings to improve the design models of objects when determining the forces and deformations in their elements. A vital indicator in monitoring the structural characteristics of buildings is global stiffness. Natural frequencies determined by modal analysis are used to detect its change. The purpose of this study is a numerical analysis of the effect of changes in the parameters of the soil base on the natural frequencies and values of vibrations of multi-storey reinforced concrete frame buildings using software systems. In this study, four variants of design models with rigidly fixed foundations and elastic foundations with different types of soils were developed.In the models with elastic foundations, stable soils were used, such as sandy, moderately stable, represented by loams and sandy loams, and weak soils containing a layer of peat. The building scheme was developed using the SCAD software package with the application of the finite element method. Taking into account that 90% of the territory of Ukraine is located in complex engineering and geological conditions, the use of the finite element method allows to effectively solve complex problems of interaction of heterogeneous elements, including in a nonlinear approach. As a result, it was found that the type of soil foundation affects the change in the natural vibration frequencies of a building. In the model with a rigidly fixed foundation, the frequencies are the highest, and the eigenvalues of oscillations are the lowest. A point that should be mentioned is that in the variants with an elastic foundation, the lowest frequencies are observed in the model on weak soils, and the highest values are typical for sandy foundation soils.

Keywords: multi-storey reinforced concrete buildings, soil base, finite element method, numerical modelling, modal analysis, natural frequencies.

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Коврова В.О., Волкова В.Є. **Аналіз впливу різних типів ґрунтів на власні частоти багатоповерхових залізобетонних будівель** // Опір матеріалів і теорія споруд: наук.-тех. збірн. – К.: КНУБА, 2023. – Вип. 111. – С. 172–177.
У статті розглянуто визначення зміни глобальної жорсткості будівлі за допомогою оцінки значень власних частот з урахуванням впливу різних ґрунтових основ. Виконано аналіз впливу параметрів ґрунтової основи на власні частоти залізобетонної каркасної будівлі. У дослідженні розглянуто 4 типи розрахункових моделей із жорстко закріпленою основу та пружною основою з урахуванням стійких, помірно стійких та слабких ґрунтів. Із застосуванням методу скінчених елементів здійснено повний розрахунок багатоповерхової каркасної будівлі з подальшим виконанням модального аналізу. Встановлено тип ґрунтової основи впливає на зміну власних частот коливань будівлі. У моделі із жорстко закріпленим фундаментом частоти є найвищими, а власні значення коливань найнижчими. У варіантах з пружною основою найнижчі частоти спостерігаються у моделі на слабких ґрунтах, а найвищі значення характерні для піщаних ґрунтів основ.
Іл. 3. Табл. 3. Бібліог. 12 назв.

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The paper considers the determination of changes in the global stiffness of a building by estimating the values of natural frequencies taking into account the influence of different soil bases. An analysis of the influence of soil foundation parameters on the natural frequencies of a reinforced concrete frame building is performed. The study considers 4 types of design models with a rigidly fixed foundation and an elastic foundation, taking into account stable, moderately stable, and weak soils. Using the finite element method, a complete calculation of a multi-storey frame building was carried out, followed by a modal analysis. It was found that the type of soil foundation affects the change in the natural vibration frequencies of the building. In the model with a rigidly fixed foundation, the frequencies are the highest and the eigenvalues of oscillations are the lowest. In the variants with an elastic foundation, the lowest frequencies are observed in the model on weak soils, and the highest values are characteristic of sandy foundation soils.
Figs. 3. Tabs. 3. Refs. 12.

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