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Accounting for natural fluctuations of buildings when assessing their technical condition

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Abstract. The existing methods of measuring the natural oscillations of buildings are considered. Theoretical approaches for determining the dependence of natural oscillations on the stiffness of structures and numerical studies of frequencies and forms of natural oscillations of buildings are studied. A comparison is made between the numerical and experimental studies of the frequencies of natural oscillations. It is established that the period of the tone of natural oscillations for estimating the changes in the stress-strain state of a building or structure, as a parameter that determines its technical state, cannot be used in practice, due to imperfect methods of its determination, causing significant errors.

1. Introduction

When inspecting buildings and structures, at present, much attention is paid to the problems of cracking of structures [1-3] caused by temperature and linear deformations, as well as to the analysis of changes in dynamic parameters, including the period of the fundamental tone of natural oscillations in determining the stress-strain state buildings and structures [4-11]. However, a unified methodology that allows one to trace an unambiguous relationship between the category of the technical state of a building, determined on the basis of its stress-strain state, and changes in the pitch period of the building's own vibration is unambiguously undefined.

2. Description of the compared options

Assessment of the technical condition of the building using a dynamic approach is based on the identification of informative diagnostic signs of the state of soil bases and load-bearing structures, which serve as two parameters that change with decreasing stiffness (ΔB). As these parameters with decreasing stiffness, we consider a decrease in the natural oscillation frequency *(f)* by an amount *(Δf)* and an increase in the peak of the transfer function $\eta\ (\omega)$ [8]. The peak offset Δf is calculated by the formula:

$$\Delta f = f_p - f_f \tag{1}$$

where - the actual (experimental) frequency of the natural oscillations of the building; - design frequency of natural oscillations of a building.

In the normative technical condition of the building, in the case of using formula (1), the following condition must be fulfilled:

$$f_f \geq f_p \tag{2}$$

Taking into account the fact that the frequency of the natural oscillations of the building *f* is inversely proportional to the period of the tone of the natural oscillations *T*, expression (2) can be written in the following form:

$$T_f \leq T_p \tag{3}$$

where - the actual (experimental) frequency of the natural oscillations of the building; T_p - design frequency of natural oscillations of a building.

The period of natural oscillations of the building can be determined indirectly, by recording the values of the vibration processes of the building along three mutually perpendicular axes [12-14]. The indirect method is a measurement in which the sought-for value is not subjected to an in-house evaluation, but is calculated from the relationship between it and the measured quantities. An important circumstance for the method under consideration is the requirement that the arguments on which the estimated quantity depends are constant, known systemic errors in the results of the measurement of the arguments were excluded, and not excluded systematic errors are distributed uniformly within the given boundaries . Create measurement conditions in which the fixed parameters of the oscillatory processes in the building, depending on various operating conditions, were practically practically not realistic.

According to the studies [9], the frequency of the building's own oscillations is influenced by the magnitudes of temporary loads (snow, wind, loads from people and equipment), the substrate durability, etc. In the process of measuring dynamic parameters, it is necessary to exclude the possibility of changing the direction and amplitude of the pulsating component wind load, random dynamic and vibration loads from passing vehicles, ground base motions, etc.

3. Results and discussions

If we solve the problem of accuracy of measuring the period of the natural oscillation tone, then in order to assess the change in the technical state of the building according to the fixed value of the period of the natural oscillation tone, it is necessary to have an initial value of this parameter under the normative technical state of the building or structure. This value of the pitch period of natural oscillations can be obtained in two ways-to measure the period of the tone of natural oscillations immediately after the completion of construction, provided that the building or structure corresponds to a normative technical state or to use a model constructed using the finite element method.

In most cases, except for unique buildings and structures, the measurement of the period of the tone of natural oscillations was not performed immediately after the completion of the construction, and therefore the only possibility is to obtain the initial value of the parameter by the calculation method, using the formula:

$$T_1 = a \cdot n \tag{4}$$

where *n* - is the number of floors in the building; *a*- is a coefficient that depends on the structure of the building and the type of its foundation.

The approach to determining the period of the tone of one's own variation presented by formula (4), in the opinion of the authors of the article, is too simplistic. It is generally known that the main dynamic parameter, the period of natural oscillations of the constructive system *T*, is related to the rigidity *EJ*. Mathematically, the dependence of the period of natural oscillations *T* on the rigidity *EJ* is expressed by the formula:

$$T = k \cdot \sqrt{\frac{m}{E \cdot J}} \tag{5}$$

where *T* - the natural oscillations of the building; *k* - is a coefficient that takes into account the type of the constructive system; *m*- is the mass, *E* - is the modulus of elasticity; *J* - is the moment of inertia.

Thus, the pitch period of the natural oscillations *T* indirectly characterizes the rigidity of the system *EJ*. However, the validity of expression (5) can not be traced on buildings below 5 floors. From the standpoint of existing building codes, the oscillatory processes associated with the wind load in buildings that meet the condition $h/d \leq 10$, which include buildings of small and medium-sized storehouses, including 5-storey buildings, in principle, are not considered; here *h* is the height of the structure, *d* is its characteristic transverse dimension in the direction perpendicular to the average wind speed. Approximate data on the boundaries of the range of the natural oscillation period for buildings that are not related to emergency buildings are presented for buildings of a height of 5 floors and above.

The fact that the modulus of elasticity E of materials used in erecting buildings from stone and concrete, and, consequently, the rigidity of the system, is a value not constant, initially dependent on the load, affects the reliability of the calculated value of the pitch of natural oscillations, since concrete and brick have non-linear characteristics. In addition, the rigidity of the building and the frequency of its own oscillations is affected by the compliance of the base.

In order to determine the factors influencing the design frequency of the building's own oscillations *fp*, we present a multifactorial numerical experiment in which the following factors were varied: the compliance of the ground base; work of temporary loads; defects and damages; compliance of joints; residual deformations.

To implement the numerical experiment, the authors [8,12] carried out a computer simulation of the stress-strain state of load-bearing structures of buildings using the example of a building with a reinforced concrete frame under static and dynamic loads, which made it possible to establish the most significant factors affecting the calculated frequency of natural oscillations , and set the deviation of the calculated values from the actual values. To assess the influence of various factors on the dynamic characteristics of the building, absolutely identical frames were considered: 6-storey buildings, 16 and 17-storey buildings, and their stiffness characteristics varied. The results of the numerical experiment are shown in Figure 1.

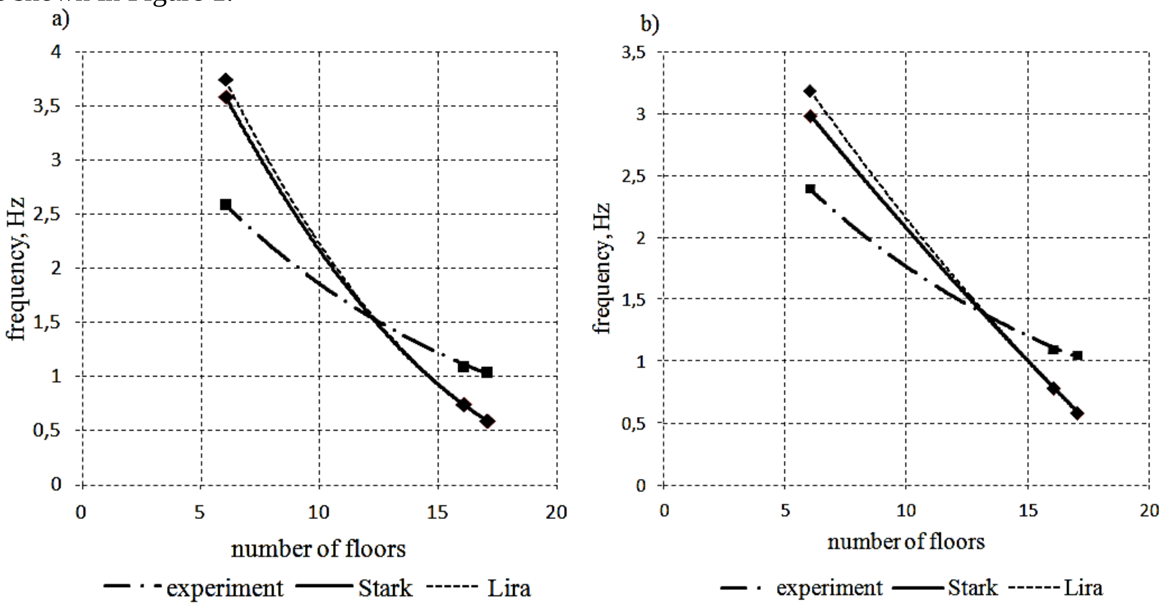

Figure 1. The graph of the change in the frequency of the building's own oscillations along the directions of the letter axes of the building: a) along the Y axis; b) along the X axis [8].

The results of the numerical experiment presented in Figure 1 show that when considering the monolithic construction of a 6-storey building, the calculated frequencies were higher than the actual (experimental) by 48%. For 16-storey and 17-storey buildings, diametrically opposite results were obtained with respect to the 6-storey building - the estimated frequencies of 16 and 17-story buildings below the actual ones by 27.5% and 34.6% respectively .

The obtained results do not trace any regularity, explaining why in one case the calculated frequencies exceed the actual ones, and in the other, they are less than the actual ones. That is, the imperfection of the calculation model takes place.

With long-term operation, there are accumulations of damage and deformation of large-panel buildings. When comparing the results of experimental studies with the data of microdynamic measurements of natural oscillation periods for different periods of operation of the surveyed buildings, the results of accumulation of physical and seismic wear were obtained in [14], Figure 2.

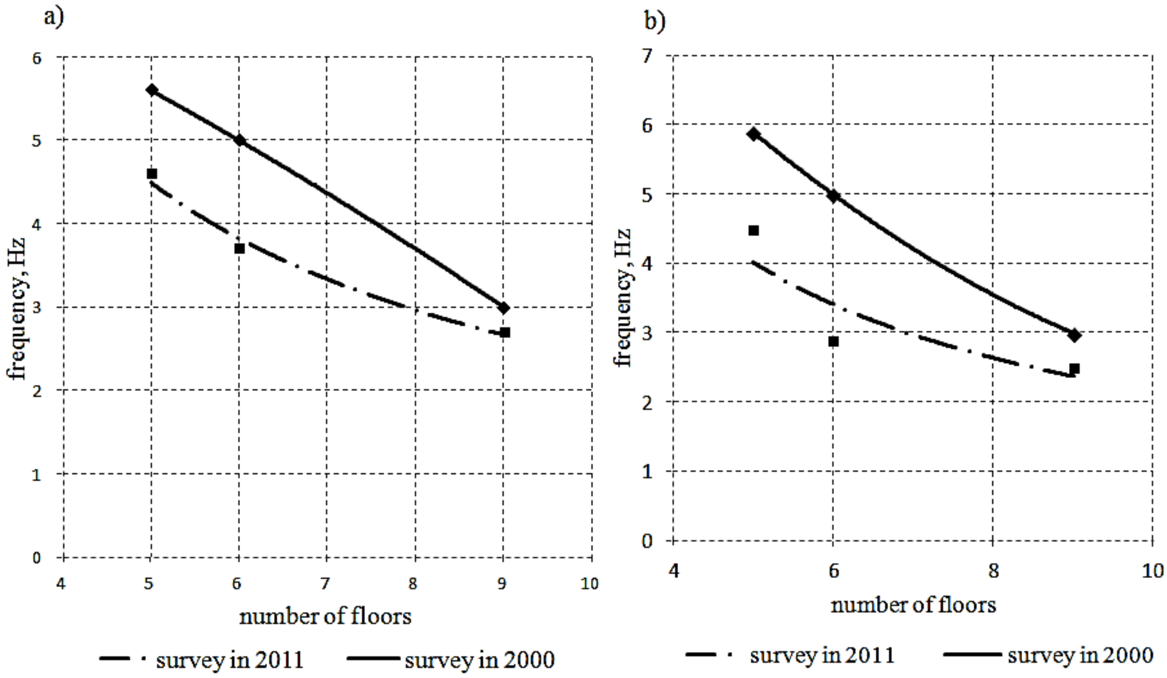

Figure 2. Change in pitch frequencies of panel buildings for 2000 and 2011: a) along the X axis; b) along the Y axis.

The calculated natural frequencies *(fp)* depend not only on the rigidity of the building itself, but also on the compliance of the ground base. At the same time, the higher the compliance of the base, the lower the frequencies of the natural vibrations of the building. The choice of the method of taking into account the compliance of the soil base leaves an imprint on the error in estimating the frequency of natural oscillations. When calculating structures that interact with a durable foundation, there is a constant problem of representing the base in the general design model of the structure and setting information on the mechanical properties of the soil massif [15].

One of the most sought-after computational models is a slab operating on a ground base subject to the basic principles of the theory of an elastic (linearly deformed) half-space. But this raises the problem of choosing the coefficients of the foundation bed, more or less adequately reflecting the real properties of the soil massif. Unfortunately, no normative document gives recommendations on determining bed coefficients even in the simplest case of a homogeneous soil massif, not to mention the most frequently encountered multi-layered foundation.

Since the calculation method for determining the reference value of the pitch period of the natural oscillation is based on the use of a certain model, and the construction of such a model is associated with the assumptions, simplifications and ignoring of a number of significant factors, then at the stage of model formation, an error is introduced into the initial value of the natural oscillation frequency of an object.

4. Conclusion

1. The period of the tone of natural oscillations for the assessment of changes in the stress-strain state of a building or structure, as a parameter that determines its technical state, cannot be used in practice, due to imperfect methods of determining it, causing significant errors;
2. Diagnostics of the technical state by the value of the period of the tone of natural oscillations in buildings that are not equipped with the automatic technical monitoring system, because of the high degree of uncertainty of results, from the category of instrumental methods passes into the category of expert methods;
3. When surveying and monitoring buildings and structures, it is necessary to abandon the measurement of the period of the tone of natural oscillations in buildings up to 16 storeys high, since the cost of the measurement process is many times higher than the cost of an engineering survey, and the result does not guarantee unambiguous and reliable conclusions on the actual technical state of the object under study;
4. The application of the vibro-diagnostic method based on the values of the pitch period of natural oscillations is possible for buildings that have a built-in automated technical monitoring system.

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