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Resonant frequency of wooden column considering support unit's flexibility

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Abstract. In the process of industrial buildings and structures designing, which constructions are also perceived by dynamic loads in addition to static loads (for example, with technological equipment), as well as in the calculation of civil buildings' structures, taking into account the pulsating component of the wind load, it is necessary to perform frequency analysis as a part of a more general dynamic analysis. The essence of frequency analysis is in the fact that it can be used in various frequency characteristics of dynamic loads. In order to avoid resonance which leads to the destruction of structures, the frequency range of dynamic load must not coincide within the range of natural oscillations frequencies of structures. The conducted researches allow us to speak about influence of pliable connections on frequency characteristics. Therefore, an urgent topic is the study of support constraints' compliance effect on natural oscillations frequencies of building constructions.

1. Introduction

In the process of design schemes compiling of buildings and structures' structural elements, two conditions of support are used — hinged and rigid. However, the rigid coupling of elements in real constructions has certain flexibility, at least at the level of strain-compression or bending deformations. Such support schemes with corresponding design of joints adequately reflect the actual conditions for their fixing for building structures made of reinforced concrete and metal. For these materials, the deformations (the relative angles of the rod rotation) in a joint are neglected due to the high resistance of metal and concrete to collapse of contact surfaces and the large values of these materials' elasticity moduli.

In order to account for buckling and a relatively low modulus of elasticity, flexibility of joints with rigid assemblies cannot be neglected for building structures made of materials with reduced resistance (like wood). The very concept of "rigid coupling", when there is no section rotation in the joint, is unacceptable to structures made of such materials.

If we talk about the cantilever beam (the simplest statically determined system with a rigid support joint), then the flexibility of the support significantly increases the deflections. In statically undetermined systems, due to the flexibility of the support, a forces' redistribution takes place [6], and the identification of its nature seems to be quite an urgent task.

Thus, the purpose of the research is to identify, on the basis of theoretical and experimental studies, the relationship between the flexibility of support joints and the natural frequency of building (AG: natural frequency refers to the building as a whole, and not the elements).

1. To consider existing methods for obtaining natural frequencies.
2. By means of numerical methods to study the influence of the support flexibility on the natural frequency, to plot the relationship between the fundamental frequency and the flexibility of support, to derive an analytical relationship between the aforementioned parameters.
3. To determine the natural frequency of a particular construction by experiment, to determine the support flexibility; to draw conclusions about the support flexibility effect of experimental construction on the fundamental frequency.

2. Conducting an experimental study

In order to assess the effect of the support flexibility on the design parameters of a building structure, wood materials having a lower resistance to buckling and a relatively low modulus of elasticity are the most suitable, therefore, a wooden column, clamped on a support using an inclined pasted steel rods in the CNIISK system was chosen for this research.

For the tests the column is adopted with a nominal size of 100x200 mm (after gouging 95x197 mm). The height of the column is HC = 1680 mm. Rods made of reinforcing steel A400 with a diameter d = 10 mm are glued at an angle of 30 degrees to wood fibers.

The experiment is conducted in 2 stages:

- the first stage is determination of the natural frequency;
- the second stage is carrying out static tests of the column and calculating the flexibility of the support joint.

The laboratory installation consists of a test bench made in the form of a steel frame. In fact, it consists of the observed column, jammed on the stand by means of obliquely pasted rods in the CNIISK system, and also of power and recording instruments used at each stage of the experiment, respectively.

In order to model a rigid base, the frame of the stand was preliminarily reinforced with a welded I - beam being welded into the space between lower crossbar elements of the stand frame and joined with them by welding to the corresponding elements stiffeners of connecting plates.

So, at the first stage of the experiment (the general view of the laboratory setup is shown in Figure 1), the frequency of the column was determined using accelerometer BC 201 [3, 5]. Sensors were fixed consistently on the head of column and near the support joint. Oscillations were created by striking in the head of the column. The obtained frequency values were 37.62 Hz, while the theoretical value for absolutely rigid support joint is 42.18 Hz (the difference is 10.8%).

At the second stage of the experiment (see Figure 2) static tests of the column were performed; the results were used for the calculation of the angular flexibility of support joint.

The column was loaded using a ratchet mechanism, one end attached to the stand, and the other to the dynamometer rail included in the chain. The load was applied to the head of the column through a steel clip 10 cm wide to avoid the crushing of the timber. The movements of the column were fixed at three points with the help of Maximov's deflectometers.

Using the static tests' results the displacement diagrams have been obtained in each of the chosen points and the obtained values were compared with the theoretical ones received from the calculation results in the software package, taking the support joint of the column absolutely rigid.

The flexibility of support joint was determined by selection method in the SCAD software package 21.1.1.1. The column model was built with a setting in the support joint of hinge with an elastic-flexible support joint of finite angular stiffness. The method of iterations was chosen to obtain an angular stiffness, where the displacement curve best corresponded to the values obtained from the results of static tests. The angular stiffness value was 1250 $kN \cdot m \cdot rad^{-1}$. Flexibility, corresponding to this stiffness, is 0.0008 $rad \cdot (kN \cdot m)^{-1}$.

Figure 1. General view of the laboratory installation used to determine the natural frequency of the wooden column.

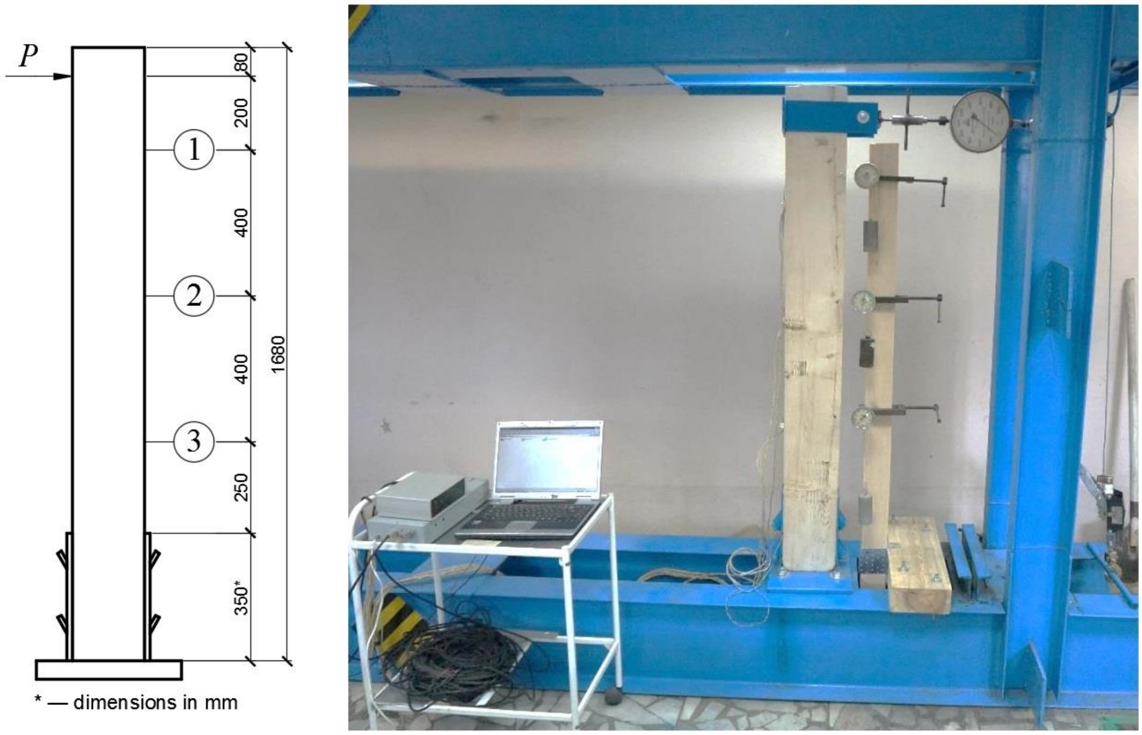

Figure 2. Scheme and general view of laboratory installation in static tests; 1, 2, 3 are the deflectometer number; *P* is the load.

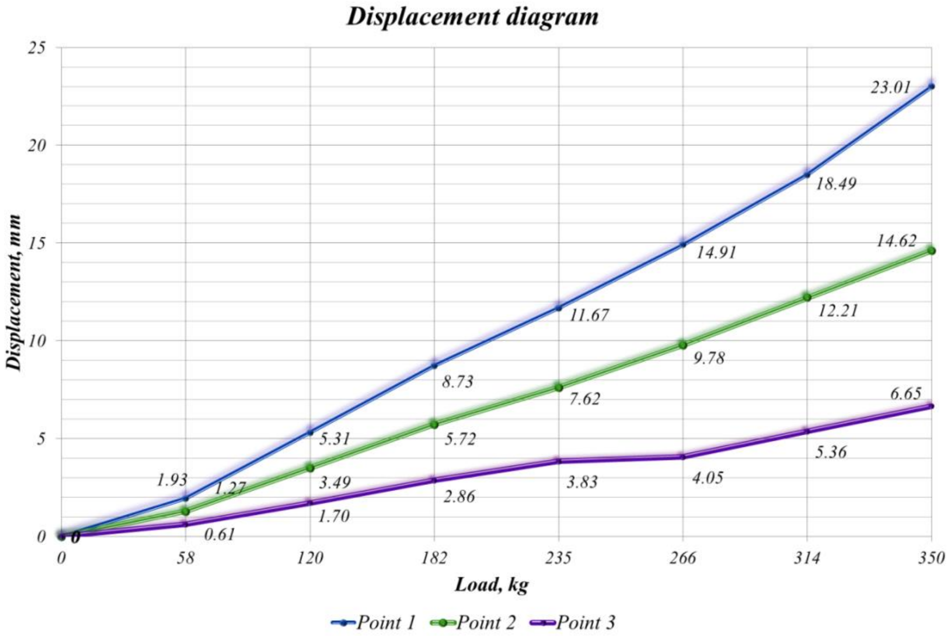

Figure 3. Diagram of the column displacements in the static tests.

3. Carrying out a numerical experiment

A numerical experiment was performed using the SCAD 21.1.1.1 software package. In the program complex, a numerical model was set with parameters of the tested column, described above in section 2 of this article.

The numerical experiment consisted of setting different values of finite stiffness of the reference joint of the wooden column in question the and calculating the natural frequency values [9]. The results of the numerical experiment are summarized in Table 1.

Table 1. Theoretical values of the natural frequency as a support flexibility function.

Number of test	Stiffness (kN·m·rad^{-1})	Flexibility (rad·(kN•m)$^{-1}$)	Frequency (Hz)
1	2	3	4
1	250	0.00400	24.32
2	500	0.00200	28.9
3	750	0.00133	31.1
4	1000	0.00100	32.4
5	1250	0.00080	33.26
6	1500	0.00067	33.86
7	1750	0.00057	34.32
8	2000	0.00050	34.68
9	2250	0.00044	34.96
10	2500	0.00040	35.2
11	2750	0.00036	35.4

Based on these data of the numerical experiment, the frequency was plotted against the flexibility of the support joint has been designed (see Figure 4).

The approximation of the obtained dependence was determined in Microsoft Excel in the following form:

$$\nu = -4.45 \ln C + 0.13$$

where C is the flexibility value of the reference joint; ν is the natural frequency.

If support flexibility isn't taken into account, theoretical first frequency of the column, as it is mentioned above, is 42.18 Hz, while the experimental frequency is 37.62 Hz (difference is 10.8 %). Such a significant difference can be explained by crushing of wood at the point of contact with the metal vertical support plates, as well as flexibility of the plates themselves. It results in appearing of non-absolutely rigid support unit, which has angular flexibility 0.0008 rad·(kN·m)$^{-1}$.

From the point of view of building structures designing, such a value of support unit flexibility is not a critical indicator, since it goes to reserve for a calculated load-bearing capacity. However, from the point of view of vibration diagnostics of structures aimed at assessing the stiffness of a constrictive system over resonance frequencies, such a difference can be significant. Therefore, it is necessary to take into account the actual joint flexibility when planning dynamic tests.

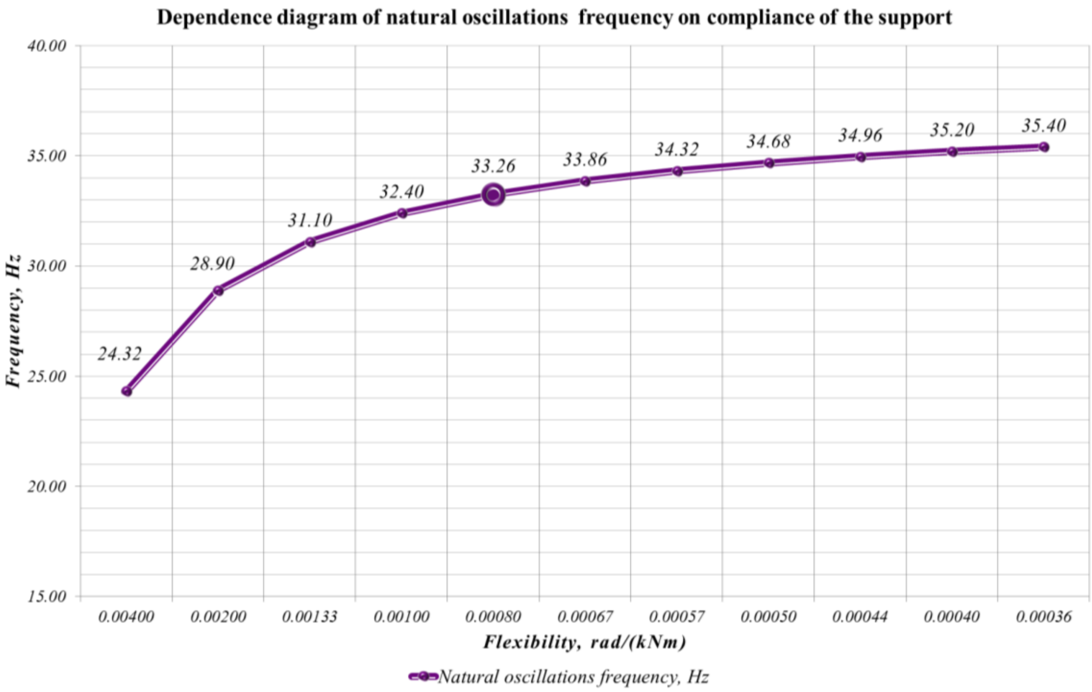

Figure 4. Natural oscillation frequency against the support flexibility.

4. Conclusions

Based on results of the work, the following conclusions are drawn.

1. Based on the results of numerical studies, the relationship between the fundamental frequency and flexibility of a support is obtained. An analytical approximation is established between the aforementioned parameters.

2. Based on the results of experimental studies, the natural frequency of the tested column is determined [8], the obtained value is compared with the value obtained from the calculation results in the software package.

The result of the work is the accumulated experience in testing of building structures, as well as the obtained relationship. This relationship shows that lower values of frequencies correspond to the higher values of the support joint's flexibility.

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