THE EFFECT OF INTERNAL FRICTION OF STRUCTURES ON THE VIBRATION OF BUILDINGS UNDER SEISMIC EFFECTS

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Abstract: *In this article was studied the task of the effect of internal friction of structural materials on the vibrations of the multi-storey building. As an example was studied five-storey brick and large-panel building with and without internal friction of materials of the constructions at the seismic effects in various frequency intensity of the base vibrations.*

Key words: *Vibrations, dynamic characteristics, internal friction, viscoelastic model, absorption coefficient, vibration decrement, vibration duration, vibration period, earthquake intensity.*

INTRODUCTION

The advancement of seismic resistance calculation methods for buildings significantly depends on the extent of understanding of free and forced vibrations, analysis of internal forces of planar and spatial models under seismic loads, development, and enhancement of methods for calculating dynamic characteristics. These characteristics, to a large extent, determine the seismic load on the building in spectral analysis, and the behavior of the building under seismic effects of various intensities in the calculation for real seismic impact. Additionally, in determining seismic loads, it is necessary to analyze the natural and forced vibrations of buildings with or without considering the internal friction of construction materials, which significantly influence their dynamic characteristics [1-2].

It is known that the foundation of regulatory documents for earthquake-resistant construction is the spectral theory of seismic resistance, based on static calculations of structures as elastic cantilever systems. However, compliance with the regulated requirements regarding the quality of materials, the volumetric-planning solution of the structure, and spectral static calculations are necessary conditions for ensuring the seismic resistance of the structure under seismic loading [3].

Based on the results of theoretical and experimental studies, a regularity has been established regarding the consideration of internal friction of construction materials, which significantly affects vibrations during seismic events [4]. The absorption coefficients of structures during building vibrations, categorized by construction types for practical use, are extensively detailed in [5].

This article addresses the problem of the influence of internal resistance on the vibrations of multi-story buildings subjected to seismic base excitation with varying frequency intensities.

2. Materials and methods

This article addresses the issue of the influence of internal friction in construction materials, considering both elastic and viscoelastic properties based on the Kelvin-Voigt model, on the dynamic characteristics of buildings using the traditional cantilever structural calculation scheme. In the calculations aimed at investigating dynamic characteristics, a system of vibration equations has been formulated both with and without considering the resistance of the floors. This system is based on the structural calculation scheme represented as a cantilever elastic and viscoelastic rod with concentrated masses, as illustrated in Figures 1-2.

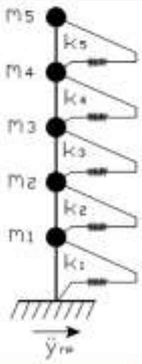
Figure 1. Calculation scheme considering the elastic properties of building floors

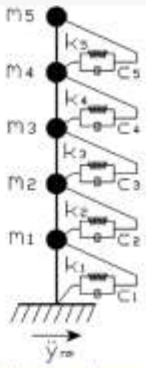
Figure 2. Calculation scheme considering the viscoelastic properties of building floors

In the research, numerical calculations were conducted to solve the problem of forced vibrations of a planar building model, both without and with consideration of the internal friction of construction materials under seismic effects. The influences of accounting for the elastic and viscoelastic properties based on the Kelvin-Voigt model of building floors on the dynamic characteristics of the building were studied using the traditional calculation scheme depicted in Figures 1-2.

The system of vibration equations for a five-story building according to the calculation scheme shown in Figures 1 and 2, without and with consideration of the internal friction of construction materials under seismic effects, is as follows [6]:

$$\begin{cases} m_n\ddot{y}_n + k_n(y_n - y_{n-1}) = -m_n\ddot{y}_{gr} \\ m_{n-1}\ddot{y}_{n-1} - k_n(y_n - y_{n-1}) + k_{n-1}(y_{n-1} - y_{n-2}) = -m_{n-1}\ddot{y}_{gr} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ m_2\ddot{y}_2 - k_3(y_3 - y_2) + k_2(y_2 - y_1) = -m_2\ddot{y}_{gr} \\ m_1\ddot{y}_1 - k_2(y_2 - y_1) + k_1 y_1 = -m_1\ddot{y}_{gr} \end{cases} \quad (1)$$

$$\begin{cases} m_n\ddot{y}_n + C_n(\dot{y}_n - \dot{y}_{n-1}) + k_n(y_n - y_{n-1}) = -m_n\ddot{y}_{gr} \\ m_{n-1}\ddot{y}_{n-1} - C_n(\dot{y}_n - \dot{y}_{n-1}) + C_{n-1}(\dot{y}_{n-1} - \dot{y}_{n-2}) - k_n(y_n - y_{n-1}) + k_{n-1}(y_{n-1} - y_{n-2}) = -m_{n-1}\ddot{y}_{gr} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots \\ m_2\ddot{y}_2 - C_3(\dot{y}_3 - \dot{y}_2) + C_2(\dot{y}_2 - \dot{y}_1) - k_3(y_3 - y_2) + k_2(y_2 - y_1) = -m_2\ddot{y}_{gr} \\ m_1\ddot{y}_1 - C_2(\dot{y}_2 - \dot{y}_1) + C_1\dot{y}_1 - k_2(y_2 - y_1) + k_1 y_1 = -m_1\ddot{y}_{gr} \end{cases} \quad (2)$$

where: y_i - represents the displacements of floors; $\dot{y}_i$ - represents the velocities of floors; $\ddot{y}_i$ - represents the accelerations of floors; $\ddot{y}_{gr}$ - represents the acceleration of the ground foundation; k_i (i -1,2,3,….n-1, n) – represents the shear stiffness of floors; m_i - represents the masses of floors; C_i - represents the damping coefficients of floors.

In the system of equations, the seismic isolation resistance force is considered according to the elastic and viscoelastic Kelvin-Voigt models, as described in [7].

The expression for the elastic and viscoelastic properties of the building floors is as follows:

$$R = k_i \cdot y_i \quad (3)$$

$$R = C_i \cdot \dot{y}_i + k_i \cdot y_i \quad (4)$$

3. Initial Building Parameters

To solve the problem in the article, the systems of equations (1) and (2) together with (3) and (4) were numerically solved using the standard MathCAD software package [8].

For further numerical investigations of buildings considering seismic isolation, a five-story brick building and large-panel buildings with rigid clamping, both with and without accounting for the internal friction of floors, were selected.

The calculated masses and stiffnesses of the existing five-story brick building according to the design data are as follows: m_1=698000 N·s²/m; $m_2=m_3=m_4$=495000 N·s²/m; m_5=368000 N·s²/m; $k_1=242,6\cdot10^8$; $k_2=16,08\cdot10^8$ N/m; $k_3=16,08\cdot10^8$ N/m; $k_4=16,08\cdot10^8$ N/m; $k_5=16,08\cdot10^8$ N/m, $C_1=124,3\cdot10^5$ N·s/m, $C_2= C_3= C_4=26,9\cdot10^5$ N·s/m, $C_5=23,24\cdot10^5$ N·s/m.

The calculated masses and stiffnesses of the existing five-story large-panel building according to the design data are as follows: m_1=258000 N·s²/m; $m_2=m_3=m_4$=213000 N·s²/m; m_5=190000 N·s²/m; $k_1=35,04\cdot10^9$ N/m; $k_2=k_3=k_4=26,846\cdot10^9$ N/m; $k_5=26,846\cdot10^9$ N/m, $C_1=90,84\cdot10^5$ N·s/m, $C_2=C_3=C_4=72,24\cdot10^5$ N·s/m, $C_5=68,23\cdot10^5$ N·s/m.

Seismic effects in the calculations are taken in the form of decaying acceleration [9]

$$y_{гр}(t) = Ae^{-\alpha t} \sin \frac{2\pi}{T} t \qquad (5)$$

where: A - the amplitude of ground acceleration, which is adopted for intensity level 9 in the calculations, is taken as 0,4g (g=9,81 m/s²), a - the damping of the ground adopted in the calculations is a=0.15; T - the period of soil oscillation adopted in the calculations for low-frequency oscillations is T=0,5 s, for high-frequency oscillations, the value of the ground oscillation period adopted in the calculations is T=0,2 s.

4. Results of Calculation

Based on the conducted numerical calculations, graphs of displacements and shear forces at the upper level of both brick and large-panel buildings over time were constructed, considering various intensities of foundation vibration frequencies under seismic effects (Figure 3-10).

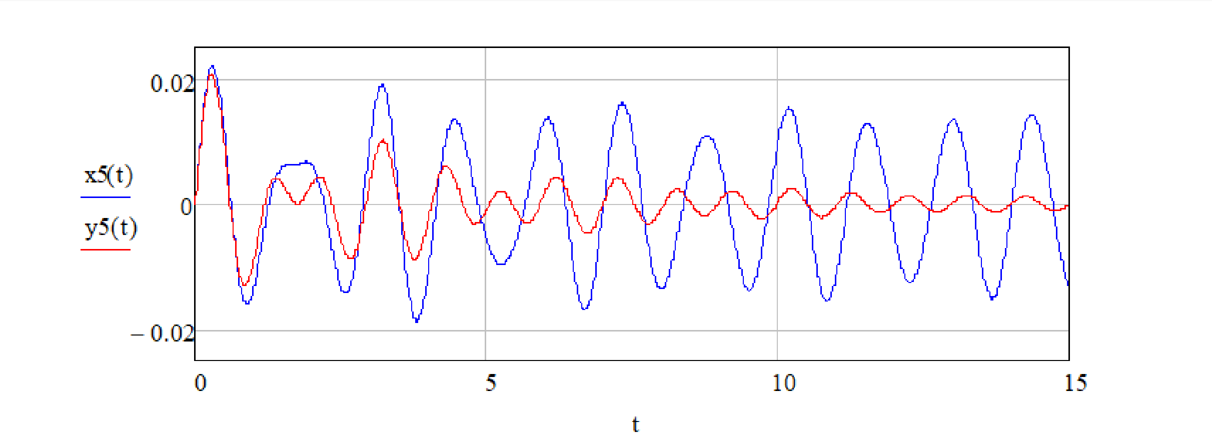

Figure 3. Displacement of the upper floor of the brick building over time during high-frequency oscillations: x5 - floor resistance assumed according to elastic law; y5 - floor resistance assumed according to viscoelastic law, m

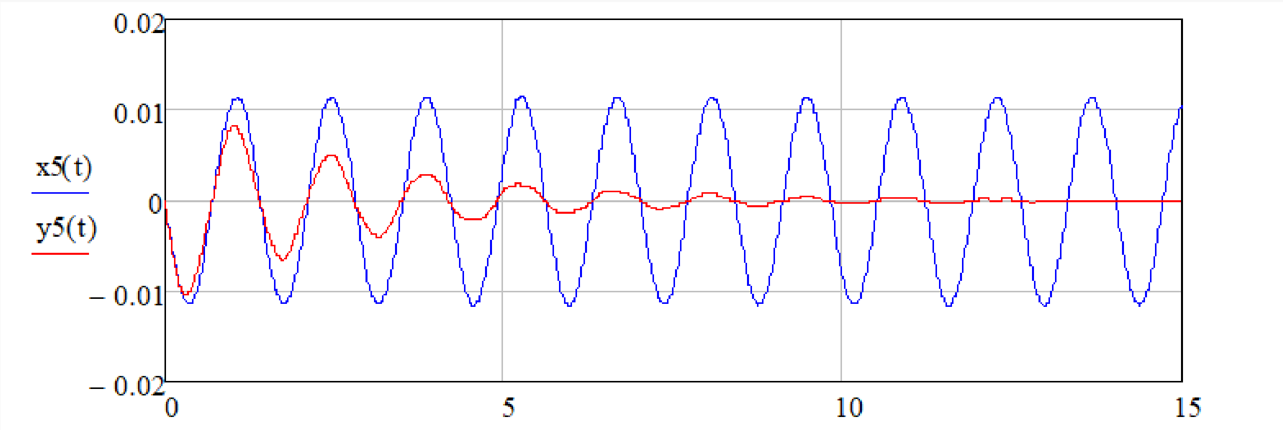

Figure 4. Displacement of the upper floor of the brick building over time during low-frequency oscillations, m

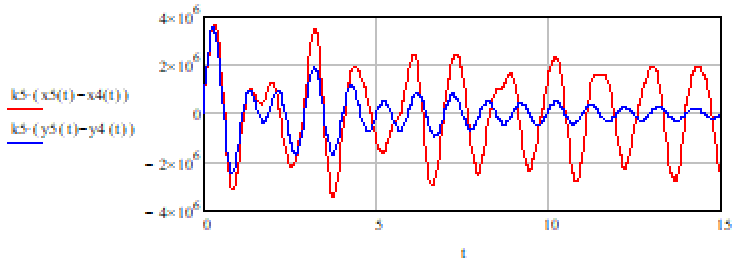

Figure 5. Shear force of the upper floor of the brick building over time during high-frequency oscillations: *k5(x5(t)-x4(t))* - floor resistance assumed according to the elastic law; *k5(y5(t)-y4(t))* - floor resistance assumed according to the viscoelastic law, N

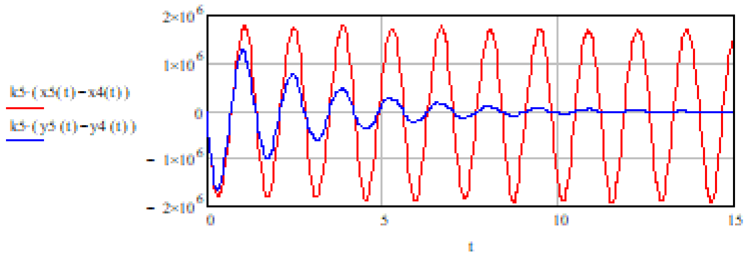

Figure 6. Shear force of the upper floor of the brick building over time during low-frequency oscillations, N

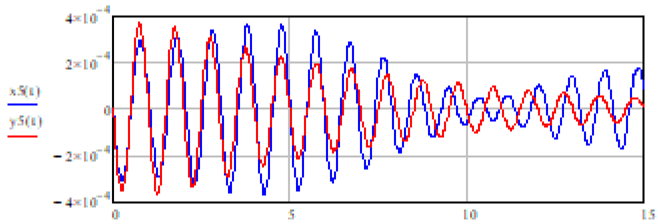

Figure 7. Displacement of the upper floor of the large-panel building over time during high-frequency oscillations: x5 - floor resistance assumed according to elastic law; y5 - floor resistance assumed according to viscoelastic law, m

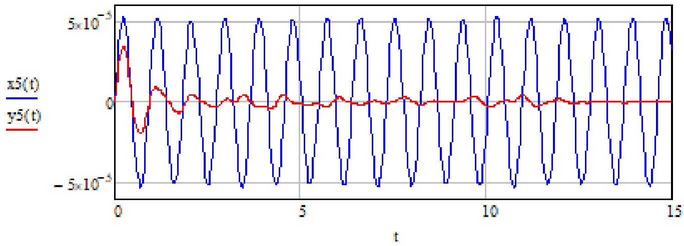

Figure 8. Displacement of the upper floor of the large-panel building over time during low-frequency oscillations, meters

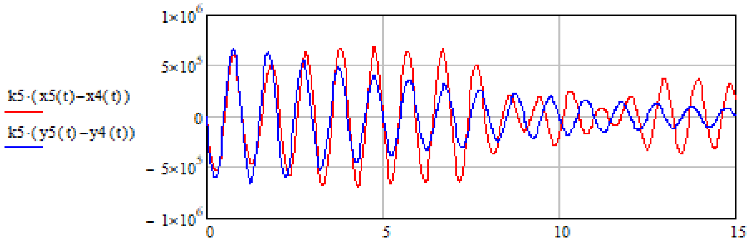

Figure 9. Shear force of the upper floor of the large-panel building over time during high-frequency oscillations: *k5(x5(t)-x4(t))* - floor resistance assumed according to the elastic law; *k5(y5(t)-y4(t))* - floor resistance assumed according to the viscoelastic law, N

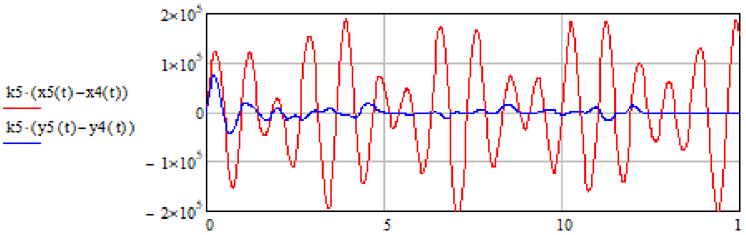

Figure 10. Shear force of the upper floor of the large-panel building over time during low-frequency oscillations, N

Figure 10. Shear force of the upper floor of the large-panel building over time during low-frequency oscillations, N

When comparing the numerical results of calculations for a five-story brick building and a large-panel building without and with considering the internal friction of construction materials under seismic effects of different frequency spectra of ground vibrations, the following differences were identified:

During high-frequency ground oscillations, the displacement of the upper floor of the brick building, considering the elastic properties of the floors, was 0.025 m, and considering the viscoelastic properties of the floors, it was 0.021 m. In this case, the duration of the building's oscillations was 15 s. Additionally, during low-frequency oscillations, considering the elastic properties of the floors, the displacement was 0.012 m, and considering the viscoelastic properties of the floors, it was 0.008 m. In this case, the duration of the building's oscillations was 8 s.

During high-frequency ground oscillations, the shear force on the upper floor of the brick building, considering the elastic properties of the floors, was 3.6•106 N, and considering the viscoelastic properties of the floors, it was 3.4•106 N. Additionally, during low-frequency oscillations, considering the elastic properties of the floors, the shear force was 1.8•106 N, and considering the viscoelastic properties of the floors, it was 1.2•106 N.

For the upper floor of the large-panel building during high-frequency ground oscillations, considering the elastic properties of the floors, the displacement was 0.00038 m, and considering the viscoelastic properties of the floors, it was 0.00028 m. In this case, the duration of the building's oscillations was 10 s. Additionally, during low-frequency oscillations, considering the elastic properties of the floors, the displacement was 0.000052 m, and considering the viscoelastic properties of the floors, it was 0.000031 m. In this case, the duration of the building's oscillations was 6 s.

The shear force on the upper floor of the large-panel building during high-frequency ground oscillations, considering the elastic properties of the floors, was 7.2•105 N, and considering the viscoelastic properties of the floors, it was 6.8•105 N. Additionally, during low-frequency oscillations, considering the elastic properties of the floors, the shear force was 1.2•105 N, and considering the viscoelastic properties of the floors, it was 0.6•105 N.

ANALYSIS AND CONCLUSIONS

As a result of the analysis, it was determined that the shear stiffness of the brick building is 10 times smaller than that of the large-panel building. Consequently, when comparing the numerical values of floor displacements, significant differences were observed.

The calculations revealed that during low-frequency oscillations, the values of displacements and shear forces decrease by almost half compared to high-frequency oscillations during seismic events.

During low-frequency oscillations, considering both elastic and viscoelastic properties of the floors significantly affects the building's vibrations under seismic conditions. Therefore, in practical calculations, it is necessary to consider all parameters influencing their dynamic characteristics as much as possible when studying building vibrations.

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