Dynamic Comfort Inside the Building under Microseismic Influence from the Movement of Vehicles

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Abstract. Vibration and it’s high background bring a danger to human health. According to the intensity of fluctuations in the urban environment transport, especially trams, trains, including metro bring the greatest impact on human. This article investigates the reaction of high-rise building on microseismic influence of the motion of the external transport. There are determined the minimum reserves of dynamic comfort for different frequencies of impacts, as well as potentially dangerous average frequencies for the studied building. A comparison of the results of the calculation of the building using explicit and implicit schemes of integration of the equations of motion is made. Conclusions about the feasibility of using implicit integration schemes for solving problems of this type are made.

1. Introduction

Among the rather large number of harmful and dangerous factors affecting a person, there are those with which we face every day. One of these factors is vibration [1,2,3]. Issues of compliance with the level of vibration in buildings and structures are as important as ensuring the bearing capacity of the structure as a whole.

In view of the greatest economic profit buildings often design high or high-rise, and due to the lack of free land for construction, most of the new facilities are located close to the metro, roads, Railways, tram tracks (figure 1). This location of objects leads to an increased level of vibration inside them from traffic [4,5].

To ensure dynamic comfort inside the building should not exceed the levels of acceleration and vibration [6,7,8]. Limit values of these indicators are specified in normative documents [9,10]. In most cases, the forecast level of vibration at the design stage is very conditional and, often, buildings require vibration protection devices after the construction of their frame [11,12,13,14]. These design flaws have a negative impact on people and require expensive options for subsequent protection [15,16,17,18].
2. Relevance
To more accurately determine and assess the level of vibration inside buildings and structures at the design stage, it is necessary to apply appropriate methods and methods of calculation [19,20,21]. Currently, there are no specific guidelines and recommendations in the design standards for the calculation of buildings and structures on the dynamic effects of traffic and the assessment of dynamic comfort inside them [1]. In the framework of this study, on the example of the building of the exhibition center (figure 2), we consider the main points of calculation and analysis of the dynamic comfort of people inside buildings and structures from external transport:
- run a structural analysis of the building by the second limit state and check for the compliance with vibration-related health standards for the design of buildings and structures;
- compare the results of design calculations for facilities by dynamic impact through explicit and implicit schemes of integration of motion equations.

3. Problem statement
A spatial design finite element model was applied to design the building. We performed calculations considering geometric and physical nonlinearities in the dynamic setting. The finite element model of the building and the longest console section are shown in figure 3.
The basic design solutions of the facility are described in table 1.

### Table 1. The basic design solutions of the facility.

| Structural layout of the building | Frame-braced |
|-----------------------------------|--------------|
| Dimensions in plan, m             | 126 x 45.6   |
| Number of floors                  | 18           |
| Length of the longest console section, m | 35.1    |
| Compression strength class of concrete for walls, cores and slabs | B60 |
| Grade of steel for elements of the main frame | C440 |
| Grade of steel for beams          | C345         |

4. **Theoretical part**

The dynamic comfort of people inside the building from traffic is checked by calculations for a special combination of loads and impacts, including all constant loads, long-term temporary, as well as the corresponding dynamic impact. Load reliability factors, load combination factors and a reliability factor for building criticality are assumed equal to one.

Permanent loads are set to:
- weight – in accordance with the density of materials (for steel – 7.850 kg/m³; for concrete structures – 2.500 kg/m³);
- load from the weight of the floating on the beam and roof on the cover – 5.474 kN/m²;
- load from the weight of the people and the equipment on overlapping – 1.648 kN/m².

On the basis of statistical data on the frequency range of oscillations generated by vehicles [22,23,24,25], a graph of microseismic influence was synthesized (figure 4).

In the calculations, damping was taken into account, which for steel structures is equal to 1% of the critical damping, which corresponds to the value of the inelastic resistance coefficient $\gamma = 0.03$ and the logarithmic vibration decrement $\delta = 0.08$. 
5. Practical relevance
The calculations for the building were performed on LS-DYNA PC [26]. We used both explicit and implicit schemes of integration for motion equations. To further analyze the results, we determined basic parameters of vibrations, which included vibration velocity and vibration acceleration in the corresponding frequency range.

The main results of the calculation are presented in the article below. Figure 5, 6 shows the reaction graphs of the building console under microseismic influence.

**Figure 5.** Graphs of vibration acceleration A – implicit scheme (red line); B – explicit scheme (green line).

**Figure 6.** Graphs of vibration velocity at the grid point A – implicit scheme (red line); B – explicit scheme (green line).
Graphs of the reaction of the building console to the microseismic influence in the zone of steady-state oscillations are shown in figure 7, 8.

Figure 7. Diagrams of vibration acceleration at the grid point in the zone of steady vibrations A – implicit scheme (red line); B – explicit scheme (green line).

Figure 8. Diagrams of vibration velocity at the grid point in the zone of steady vibrations A – implicit scheme (red line); B – explicit scheme (green line).

According to the results of calculations, a comparative table of vibration accelerations and vibration velocities at the studied point was compiled (table 2).

Table 2. Comparative table of the vibration acceleration and vibration velocity at the grid point.

| Geometric average frequencies of bands, Hz | Maximum vibration acceleration $a_{max}$, m/s$^2$ | Ultimate vibration acceleration $a_{ult}$, m/s$^2$ | Factor of dynamic comfort | Maximum vibration velocity $v_{max}$, m/s$^{10^2}$ | Ultimate vibration velocity $v_{ult}$, m/s$^{10^2}$ | Factor of dynamic comfort |
|-----------------------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------|-----------------------------------------------|-----------------------------------------------|--------------------------|
| 1.6                                     | 0.0003                                        | 0.013                                         | 43.33                    | 0.002                                         | 0.13                                          | 65.00                    |
| 2                                       | 0.0008                                        | 0.011                                         | 13.75                    | 0.004                                         | 0.089                                         | 22.25                    |
| 2.5                                     | 0.0034                                        | 0.01                                           | 2.94                     | 0.01                                          | 0.063                                         | 6.30                     |
| 3.15                                    | 0.0031                                        | 0.0089                                         | 2.87                     | 0.01                                          | 0.045                                         | 4.50                     |
| 4                                       | 0.0018                                        | 0.0079                                         | 4.39                     | 0.008                                         | 0.032                                         | 4.00                     |
| 5                                       | 0.0012                                        | 0.0079                                         | 6.58                     | 0.004                                         | 0.025                                         | 6.25                     |
| 6.3                                     | 0.0017                                        | 0.0079                                         | 4.65                     | 0.004                                         | 0.02                                          | 5.00                     |
| 8                                       | 0.0021                                        | 0.0079                                         | 3.76                     | 0.004                                         | 0.016                                         | 4.00                     |
| 10                                      | 0.0025                                        | 0.01                                           | 4.00                     | 0.003                                         | 0.016                                         | 5.33                     |
According to the table 2, graphs were constructed in the dynamic margin of comfort in calculating the microseismic influence (figures 9, 10).

| Frequency | 12.5 | 16 | 20 | 25 | 31.5 | 40 |
|-----------|------|----|----|----|------|----|
| Vult/Vmax | 0.0061 | 0.0056 | 0.0055 | 0.0076 | 0.0081 | 0.0078 |
| vmax     | 0.013 | 0.016 | 0.02 | 0.025 | 0.032 | 0.04 |
| Geometric mean frequencies of bands, Hz | 2.13 | 2.86 | 3.64 | 3.29 | 3.95 | 5.13 |
| 2.67 | 3.20 | 5.33 | 8.00 | 8.00 | 8.00 |

\[ \frac{V_{ult}}{V_{max}} \]

\[ v_{max} \]

\[ \text{Geometric mean frequencies of bands, Hz} \]

**Figure 9.** The diagrams of the factor of dynamic comfort in calculating the impact of pedestrian traffic by vibration acceleration.

**Figure 10.** The diagrams of the factor of dynamic comfort in calculating the impact of pedestrian traffic by vibration velocity.

### 6. Conclusions
Based on the results, the following conclusions can be done:
1) When exposed to the building microseismic influence from the movement of vehicles comfort condition is met. Minimal amounts of 2.13 at a frequency of 12.5 Hz. Potentially dangerous can be the average frequency in the range from 2.5 Hz to 40 Hz;
2) The calculation of the building on the microseismic influence from the movement of vehicles in the implementation of explicit and implicit schemes of integration of the equations of motion gives a discrepancy in the results for the acceleration and vibration speeds of 2 and 1.4 times, respectively;
3) The design of buildings and structures for vibration by a direct dynamic method should include implicit schemes of integration for motion equations to avoid large errors in the calculated results.

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