Monitoring the behavior of a high-rise building under wind loads

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Abstract. To assess the ecological risk parameters, instrumental measurements of the intrinsic characteristics and vibration amplitudes of the 34-storey high-rise building "Transport Tower" in the city of Nur-Sultan were performed under wind loads. The observation interval is two days. The measurements were carried out using a digital instrumentation system. Acceleration values measured at the top of the building over two days of monitoring. An excess of the comfortable level of 8 cm/s² was detected. When measuring the values of the kinematic characteristics, an acceleration value of 9.23 cm/s² was recorded. The experimental and theoretical periods of vibration of the building in the first and second modes of vibration are determined. To reduce the level of accelerations under wind loads, it is suggested to use vibration dampers or viscous vibration dampers.

1. Introduction

Buildings and structures placed in the air flow are subjected to the action of aerodynamic forces, which can be determined using solutions to problems of theoretical aerodynamics and the results of experimental studies. Any methods of structure dynamics can be used to determine the responses of structures.

The reaction of a building caused by the frontal resistance to the wind is commonly referred to as the reaction in the direction of the wind. Resonant amplification of a building's response to forces caused by atmospheric turbulence was first studied in the middle of the last century.

Currently, regulatory documents have been developed to determine the wind load coefficients for high-rise buildings [1]. Experimental observations of the behavior of tall and ultra-tall buildings are carried out [2-5]. The effect of free flow turbulence on wind loads in a full-scale large cooling tower is investigated [6]. Effective methods are being developed for assessing the effect of wind on structures on the basis of recorded pressure values [7] are studied, as well as the effects of interior burnouts in multi-storey buildings [8] and fire safety issues [9].

The best way to determine the responses of a high-rise building is to experimentally determine the kinematic characteristics of the building, i.e., acceleration, speed, movement.

The 34-storey building of the administrative and technological complex "Transport Tower", located on 32/1 Kabanbay Batyr Avenue, Nur-Sultan, is observed. The building houses the Ministry of Industry and Infrastructure Development of the Republic of Kazakhstan. Office workers felt very uncomfortable under strong wind loads.
Therefore, the task was set to assess compliance with environmental requirements. Such requirements are contained in the regulatory documents of the Russian Federation and the Republic of Kazakhstan. Linear accelerations under wind influences should not exceed 8 cm/s².

The task was set as follows:

- to carry out instrumental measurements of linear acceleration under wind loads;
- to analyze the calculated and experimental data;
- if necessary, develop recommendations for reducing the linear acceleration to permissible values.

It should be noted that this task is relevant for the capital of the Republic of Kazakhstan, the city of Nur-Sultan, where about a hundred high-rise buildings up to 40 floors have been built.

2. Object of study

The main structure of the building of the administrative and technological complex "Transport Tower" is a tower-type structure with a height of 34 floors with a developed first floor (Fig. 1). The building has the shape of an oval in plan with dimensions of 28×45 m in the laying out axises.

Under the entire volume of the building there is a ground floor with a height of 3.5 m.

From the 27th floor and above, the building has a sloping part. At the level of 128.65 m, a steel cone-shaped spire with a height of 24 m is installed.

Office premises are located in the main volume of the building. The technical floors are the 12th, 22nd and 32nd floors.

The purpose of the premises of the second stage is conference rooms, a dining room, technical rooms (pumping stations, garages, etc.).

From the first to the fifth floor, an atrium is made from the level of 0.0 m to 15.6 m.

The atrium has a panoramic lift.

To service the building, there are 8 elevators and two staircases located at the abutting ends of the building.

The structural scheme of the main volume of the building is made in the form of a girder-free frame with stiffening diaphragms.

Figure 1. General view of the building.
3. Results of experimental studies

Kazakh Scientific Research and Design Institute of Civil Engineering and Architecture carried out experimental recording of acceleration values on a 34-storey building in Nur-Sultan. The measurements were carried out using a PCM-8 digital instrumentation system with ADXL sensors. The results are shown in Figures 2-14.

**Figure 2.** Load u2 at the 31st floor level, acceleration value 9.23 cm/s², effective duration 36.11 sec, period of 2.37 seconds (recorded on 11/21/18).

**Figure 3.** Load u6 at the 27th floor level, acceleration value 0.44 cm/s², effective duration 19.58 sec, period 2.37 sec (recorded on 11/21/18).

**Figure 4.** Load u7 at the level of the 27th floor, acceleration value 0.22 cm/s², effective duration 39.9 sec, period 2.37 sec (recorded on 11/21/18).

**Figure 5.** Frequency characteristics of wind load at the level of the 27th and 31st floors, the period of the spectrum maximum is 2.37 s (recorded on 11/21/18).
Figure 6. Load u4 at the 31st floor level, acceleration value 0.27 cm/s², effective duration 44.59 sec, period 1.72 sec (recorded on 11/21/18).

Figure 7. Load u5 at the 31st floor level, acceleration value 0.18 cm/s², effective duration 45.66 sec, period 1.72 sec (recorded on 11/21/18).

Figure 8. Frequency characteristics of wind load on the 31st floor (recorded on 11/21/18).

Figure 9. Load x31-u1 at the 31st floor level, acceleration value 2.14 cm/s², effective duration 369.24 sec, period 2.37 sec (recorded on November 22, 2018).

Figure 10. Load x31-u3 at the 31st floor level, acceleration value 0.50 cm/s², effective duration 369.24 sec, period 2.37 sec (recorded on November 22, 2018).

Figure 11. Frequency characteristics of wind load at the level of the 31st floor (recorded on November 22, 2018).
Figure 12. Load x31-u2 at the 31st floor level, acceleration value 2.31 cm/s², period 1.72 sec (recorded on November 22, 2018).

Figure 13. Impact x31-u4 at the 31st floor level, acceleration value 0.49 cm/s², period 1.72 sec (recorded on November 22, 2018).

Figure 14. Frequency characteristics of wind load on the 31st floor (recorded on November 22, 2018).

Instrumental records of 11/21/18 were obtained along two horizontal axes in the azimuthal plane with amplitudes in the range of 0.18 - 9.23 cm/s². Frequency characteristics are plotted. Effective duration is within 19.58-45.66 sec. On the OX axis (transverse direction) the oscillation period along the first tone is 2.38 sec, along the OY axis (longitudinal direction) - 1.72 sec.

There are instrumental records on 22.11.18 along two horizontal axes in the azimuthal plane with amplitudes in the range of 0.49 - 2.31 cm/s². The records are very long (277300 points with a digitization step of 0.0064 sec). Frequency characteristics are plotted. Effective duration is within 330-360 sec. On the OX axis (transverse direction), the experimental period of oscillation along the first tone is 2.38 sec, along the OY axis (longitudinal direction) - 1.72 sec.

Noteworthy is the instrumental record in Fig. 11, which looks like a strongly damped signal. Another instrumental record along the same axis does not have this form (Fig. 12). However, in both cases, the period of natural oscillations along the OY axis is determined quite well from the spectral dependences.

Note also that no excessive wind effects were observed on 11/21/18 and 11/22/18.

When installing a permanent station of the engineering seismometric service, probabilistic estimates of the values of linear accelerations can be obtained in a much more accurate version.

4. Theoretical data

Numerical simulation of the behavior of a 34-storey building under wind loads has been performed. The building was modeled by a space multibody discrete system. The calculations were carried out by the finite element method using the licensed software package "Lira-CAD 2018 (R1.2)".
The calculated value of the oscillation period was 2.91 sec in the transverse direction and 2.24 sec in the longitudinal direction. The indicated values correspond to the first and second modes of vibration of a 34-storey building.

The calculated period of oscillations for the first mode of oscillation is 22% higher than its experimental value. In the second mode of fluctuation, the differences are 30%.

The difference in the values of the oscillation periods is explained by the incomplete loading of the building with payloads (stained glass windows, partitions), the participation of non-structural elements.

According to the results of calculations, the value of linear acceleration at the level of the upper elevation of the building in the transverse direction is 19.7 cm/s$^2$, which is more than twice the permissible values. Acceleration at the level of the upper elevation of the building in the longitudinal direction is 8 cm/s$^2$, which is in the range of permissible values.

Thus, the calculated values of the linear acceleration values do not contradict the experimental values.

5. Discussion

According to regulatory documents, when calculating a building for a wind load, in addition to the conditions of strength and stability of the building and its individual structural elements, restrictions on the oscillation parameters of the upper floors, due to the requirements of comfort, must be provided.

In accordance with the regulatory documents of the Russian Federation and the Republic of Kazakhstan, a high-rise building meets the requirements for comfort if the maximum value of acceleration $a_{max}$ at the level of the building's roof does not exceed 8 cm/s$^2$. Essentially, the task of assessing ecological risk is being solved.

Note that the experimental value of the linear acceleration of 9.23 cm/s$^2$ was recorded once, but on a relatively calm day. With a sufficiently strong wind load, it can be significantly exceeded.

However, the fact of exceeding the permissible linear acceleration value is established. The task has been completed.

To reduce the linear acceleration, various types of vibration dampers [10], dampers of viscous and dry friction, used in seismic isolation systems for buildings and structures [11-15] can be used. To calculate the parameters of vibration dampers, it is necessary to continue instrumental observations of the behavior of a 34-storey building under wind loads. The observation interval should supposedly be at least a year. This will make it possible to compile a statistical series for assessing the probabilistic characteristics of the values of expected accelerations under wind influences.

6. Conclusion

1. For the first time instrumental measurements obtained the values of linear accelerations in the upper part of a high-rise building on the 27th and 31st floors. The highest acceleration value is 9.23 cm/s$^2$, which is more than the comfortable threshold acceleration value of 8 cm/s$^2$. There is an adverse environmental impact on office staff in this building.

2. The experimental periods of oscillation of the building in the longitudinal and transverse directions, 2.38 sec and 1.72 sec, were determined. The indicated values are less than the calculated values of the oscillation period. The estimated oscillation period was 2.91 sec in the transverse direction and 2.24 sec in the longitudinal direction.

3. The results of records of microseismic vibrations prove that the computational theoretical model corresponds to the actual model of the building.

4. To meet the comfort requirements for linear acceleration values, it is recommended to install vibration dampers or damping devices.

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