Dynamics of a 16-storey building with a core of rigidity in a local earthquake

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Abstract. The behavior of a 16-storey residential building with a stiffness core during the earthquake of March 26, 2018 is analyzed. The building is located 100 meters from the tectonic fault. The absence of resonance phenomena of the building during a local earthquake was established. On the distribution of accelerations in the horizontal plane, the effect of “eight” was found. An increased value of acceleration in the vertical direction at the level of the technical floor was revealed. This could be due to the presence of a tectonic fault near the building. The energy characteristics of the building and the impact are determined, the Arias integral and the cumulative absolute velocity are calculated. At the basement level, the period of the spectrum maximum is of the order of 0.1 sec. It is established that the building oscillates in the sum of the vibration modes.

1. Introduction

The entire territory of the Almaty region is prone to earthquakes, which can pose a danger to buildings and structures on the territory of Almaty. In addition, high-rise buildings can sway under strong wind influences. Therefore, instrumental observations are carried out for a significant number of buildings.

The Engineering and Seismometric Service (hereinafter - ESS) in the Republic of Kazakhstan is currently represented by 12 stations, including in the city of Taraz (one station) and the city of Kapshagai (one station), located on buildings of various designs. Four stations have both digital and analogue equipment.

Old analog devices prevail at the stations. These are VBP sensors that measure velocities and displacements, and OSP sensors that record accelerations and velocities. There are also SM-4 sensors that record displacements. Currently, various measuring systems and devices have been developed [1-6]. Therefore, the modernization of the stations can in principle be carried out.

According to the operational data of the RSE Data Center of the Institute of Geophysical Research of the Ministry of Energy, on March 26, 2018 at 18 hours 53 minutes Astana time (March 26 at 12 hours 53 minutes GMT) an earthquake occurred, located 31 km southeast of Kapshagai, 63 km northeast of Almaty. The coordinates of the epicenter: 43.70 degrees north latitude, 77.36 degrees east longitude. Magnitude mpv = 5. Energy class K = 11.4. Depth h = 7 km. The earthquake was felt in the city of Almaty with an intensity of 3-4 points and much stronger in the city of Kapshagai.

Following tasks are set:

- Explore the vibrations of a high-rise building near a tectonic fault.
To identify the possibility of resonance phenomena in such buildings in case of sufficiently close local earthquakes.

To use instrumental records of a real earthquake to solve these problems.

Thus, experimental research methods (instrumental recording of accelerations) and theoretical methods based on the use of computer mathematics systems, for example, MATLAB, are combined.

2. Seismic station № 17 «Novaya ploschad» and the object of research.
The station is located on a 16-storey residential building with a core of stiffness. It should be noted that this station began operating in 1987. In 2008, the station was modernized - a digital instrumental measuring system RSM-8 with ADXL sensors was installed. The building is located about 100 meters off the tectonic fault boundary.

Footprint of the building is 20.28 m by 65.40 m.

The structural basis of the building is a frame-braced frame, inside of which there is a lattice stiffness core in the form of a spatial bar structure. The size of the core in the plan is 6790-6800 mm. The stiffness core is developed in two levels by traverses. The spatial stability of the building is ensured by the joint work of single-span frames and a lattice stiffening core. A frame-braced frame rests on columns with a section of 740x740 mm. The columns are made of M400 heavy concrete.

![Building façade](image)

**Figure 1.** Building façade.

The foundation of the building is made of precast monolithic reinforced concrete. The soil is a dense pebble-boulder.

3. Results.
In [7-8], the results of registration of earthquakes of various intensities by seismic station №17 "Novaya ploschad" are given. The earthquake of March 26, 2018 is the third recorded by a digital instrumentation system. Figures 2-10 show both the instrumental material and the calculation results.

Figures 4-5 show instrumental records (accelerograms) at the levels of the roof, 10th floor and basement. For spectral analysis of accelerograms, the MATLAB computer mathematics system is used. Spectral curves at a decrement of 0.3 are shown in Figures 6-10.
Table 1 shows the results of measurements and calculations ($h$ is the sampling step of accelerograms). The effective duration here is the duration of oscillations with an amplitude of at least half of the maximum acceleration value.

The current scale MSK-64 (K) is compiled for earthquakes with an intensity of 5-10 points. This earthquake does not fall within the specified interval in terms of the values of the registered accelerations. The indicated scale contains accelerations from 16 cm/s$^2$ to more than 900 cm/s$^2$. Here the acceleration at the basement level is 14.25 cm/s$^2$.

Therefore, it is fair to attribute the earthquake of March 26, 2018 to a seismic event with an intensity of 4 points on the territory of Almaty in the area of seismic station №17 "Novaya ploschad".

Acceleration in the horizontal plane at the level of the 17th technical floor is less than the acceleration at the basement level. A significant acceleration along the vertical axis of 29.13 cm/s$^2$ should be noted.

The spectral characteristics of the instrumental records at the basement level characterize the frequency composition of the seismic effect at the level of the building foundation. These are periods of prevailing fluctuations of 0.1 s.

Table 1. Maximum values of accelerations and parameters of accelerograms during an earthquake of March 26, 2018 ($h=0.0064$s).

| Component          | Acceleration, cm/s$^2$ | Effective duration, s | Spectral coefficient | Spectrum maximum period, s |
|--------------------|------------------------|-----------------------|----------------------|----------------------------|
| 26.03.18-17-3-u1,17th floor OX | 0.32                   | 65.69                 | 2.25                 | 0.17                       |
| 26.03.18-17-3-u2,17th floor OY | 9.83                   | 19.51                 | 3.77                 | 0.21                       |
| 26.03.18-17-3-u3,17th floor OZ | 29.13                  | 5.38                  | 6.95                 | 0.25                       |
| 26.03.18-17-3-u6,basement OY | 14.25                  | 71.27                 | 2.78                 | 0.10                       |
| 26.03.18-17-3-u7,basement OX | 8.90                   | 19.33                 | 3.60                 | 0.42                       |
| 26.03.18-17-3-u8,basement OY | 13.38                  | 18.14                 | 3.19                 | 0.22                       |

A two-component instrumental recording of an earthquake in the horizontal plane is a decomposition of the seismic action along two orthogonal axes oriented along the parts of the world or in some other direction (for example, along the axes of a building).

Therefore, the impact parameters: maximum or root mean square accelerations, frequency composition (visible or dominant periods) are studied from the projections of the seismic impact on these axes. Consequently, the information about the impact parameters obtained in this way is to a certain extent random in nature, since by turning around the axis, a new coordinate system can be obtained, in which the projections of the acceleration vector can have other, very different, parameters. Therefore, the dynamic effect of an earthquake also differs depending on the orientation of the coordinate system.

Figures 2-3 show the distribution of accelerations in the horizontal plane, both at the level of the 10th floor and at the level of the roof. The angle step is $2\pi/50$. The angle varied from 0 to $2\pi$. Acceleration values were calculated at 51 points. At the level of the 10th floor, the maximum acceleration value is 14.26 cm/s$^2$, for the roof - 9.83 cm/s$^2$. In general, the acceleration values in the OY axis exceed the acceleration values in the OX axis.

Figures 6-10 show the spectral curves, both along the points of registration of accelerations, and along the axes OX and OY. The spectral curve along the OY axis at the basement level is shown separately. All of its frequencies lie in a rather narrow range of 5-10 Hz.
At level 10 and technical floors, the periods of the maximum spectrum coincide, except for the OX axis on the 10th floor.

The spectral curves along the OX axis are practically nested within each other. On the OY axis, the curves are more jagged. Three peaks are visible at the technical (17th) floor.

![Distribution of accelerations on the azimuth plane at the 10th floor level.](image1.png)

**Figure 2.** Distribution of accelerations on the azimuth plane at the 10th floor level.

![Distribution of accelerations on the azimuth plane at the 17th floor level.](image2.png)

**Figure 3.** Distribution of accelerations on the azimuth plane at the 17th floor level.

The period of oscillation according to the fundamental tone as in [7] does not appear here. The building just vibrates by the sum of the vibration modes.

Thus, there is no resonance effect on the first waveform. The source of the past earthquake is located quite close to the territory of Almaty. The earthquakes generated by it are generally of a high-frequency nature.

Note that the resonant vibrations of the building took place during a remote earthquake on August 9, 2017 with a source in China [7]. The period of fluctuation in the fundamental tone of 1.44 s was revealed. And on the second - 0.43 s. Judging by Figures 7 and 9, oscillations occur mainly with a predominance of the second oscillation mode of 0.43 s.
Figure 4. Instrumental records (accelerograms) at the level of the 17th technical floor (seismic station №17).
Figure 5. Instrumental records (accelerograms) in the basement level (the OY axis is blue) at the level of the 10th floor of the OX and OY axes (seismic station №17).
Figure 6. Spectral curves at roof level (seismic station №17).

Figure 7. Spectral curves at 10th floor level (seismic station №17).
Figure 8. Spectral curves at basement level (seismic station №17).

Figure 9. Spectral curves by OX axis (seismic station №17).
4. Discussion

Energy characteristics of an earthquake are evaluated using various parameters [9-10].

Further, to study the instrumental records of the ISS stations, as a characteristic of the earthquake, we will consider the following intensity variant according to Arias [9]:

\[ I_A = \frac{\pi}{2g} \int_0^T \dddot{y}_0^2(t)dt , \quad (1) \]

or cumulative absolute speed

\[ U = \int_0^T |\dddot{y}_0(t)|dt = \text{CAV}. \quad (2) \]

The calculation of the energy characteristics was performed using instrumental records in the building levels. The characteristics of the vibrations of the foundation (duration of exposure, spectral composition, amplitude characteristics) and the whole complex of characteristics of the impact affect the amount of energy that entered the structure and affects the damage to all its elements. The building starts to work nonlinearly and elastic pendulum models are already becoming unacceptable.

Table 2 shows the values of the energy characteristics for each of the instrumental records. The calculations were performed using the MATLAB computer mathematics system using standard procedures.

It should be noted that at the level of the 10th floor in the horizontal plane, the values of the Arias integral practically coincide. In this case, the acceleration peaks differ by about 30%.

The highest cumulative velocity is at the basement level. In this case, in the basement level, there is not the largest value of the acceleration peak.

It should be noted that the building is located near a tectonic fault. Therefore, it is advisable to equip buildings of this type with various seismic isolation systems and damping devices [11-14].

It is of undoubted interest to accumulate information on the indicated energy characteristics for a given building under various, including local, earthquakes [15]. The influence of the fault here manifests itself here in the form of increased values of the accelerations in the vertical direction.
Note that the question of changing the dynamic characteristics of this building over a 30-year period of operation of the building remains open. This issue has been almost exhaustively studied for the 25-storey building of the hotel "Kazakhstan" [16].

Table 2. Maximum acceleration values and energy characteristics of accelerograms with an earthquake on March 26, 2018, seismic station №17 (h=0.0064 s).

| Component | Acceleration, cm/s² | \( I'_A \), cm/s² | CAV, cm/s | Spectrum maximum period, s |
|-----------|---------------------|------------------|-----------|--------------------------|
| 26.03.18-17-3-u1, 17th floor OX | 0.32 | 5.45·10⁴ | 03.85 | 0.17 |
| 26.03.18-17-3-u2, 17th floor OY | 9.83 | 0.2520 | 63.67 | 0.21 |
| 26.03.18-17-3-u3, 17th floor OZ | 29.13 | 1.5217 | 95.58 | 0.25 |
| 26.03.18-17-3-u6, basement OY | 14.25 | 1.700 | 222.60 | 0.10 |
| 26.03.18-17-3-u7, 10th floor OX | 8.90 | 0.179 | 55.58 | 0.42 |
| 26.03.18-17-3-u8, 10th floor OY | 13.38 | 0.180 | 43.93 | 0.22 |

5. Conclusion
1. The distribution of accelerations in the horizontal plane at the level of the technical floor of a building with a stiffness core (seismic station №17 "Novaya ploschad") has an unusual appearance. The distribution looks like a "figure eight". This is due to the significant difference in acceleration values along the OX and OY axes.
2. The period of the spectrum maximum at seismic station №17 at the basement level equal to 0.10s characterizes the spectral composition of the seismic impact.
3. It was found that during local earthquakes, resonance phenomena on a building with a core of stiffness were not observed.
4. The seismic event on March 26, 2018 according to the instrumental records of seismic stations №17 represents an earthquake with an intensity of no more than 3-4 points in the territory of Almaty. The source of the earthquake is located in the Almaty region near the city of Kapshagai.
5. Of the possible factors influencing the presence of a fault on the structure of a building with a stiffness core (seismic station №17), it should be noted a significant value of acceleration in the vertical plane at the level of the technical floor - 29.13 cm/s².
6. For the first time for a 16-storey building with a stiffness core, an assessment of the energy characteristics was carried out under conditions of real seismic impact.

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