

# Response of rigid and flexible buildings in an earthquake

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**Abstract.** During the earthquake on March 26, 2018 with a source in the Almaty region, the stations of the engineering and seismometric service received instrumental records on buildings with various design solutions. The article discusses instrumental records (accelerograms) recorded on a four-storey frame building and an 11-storey building with a steel frame. Spectral curves were plotted at the registration points on the roof and basement parts of buildings. It was found that the periods of the prevailing fluctuations of the base of the structure are 0.16-0.21 sec for the two indicated buildings. The spectral curves at the basement level have the same shape. Instrumental records are included in the database of accelerograms of KazRDICA JSC.

## 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.

The seismic hazard of the city of Almaty is usually associated with the seismogenic zones of the Northern Tien Shan. The main ones are those located close to the city - Almaty, Zailiyskaya and Chiliko-Keminskaya zones. Their seismopotential is quite large - the possible magnitudes of the strongest earthquakes with sources in these zones are, respectively, from 7.5 to 8.5, and the intensity of earthquakes in the city can reach from 8 to 10 points. The strike of the zones coincides with the strike of the Zailiyskiy and Kungey Alatau and the Chiliko-Kemin fault zone.

The city was destroyed twice by the strongest earthquakes - Vernensky in 1887 with a magnitude of 7.2 and Keminsky, in 1911 with a magnitude of 8.2. The city has repeatedly experienced less severe earthquakes. The Zhalanash-Tyup earthquake of 1978 with a magnitude of 6.9 and the Suusamyr earthquake of 1992 with a magnitude of 7.3 could be noted. On the territory of the city, in different parts of it, they were felt with an intensity of 5-6 points [1, 2].

For a long time, there was a firm conviction that there were no earthquake foci on the territory of the city. It was believed that faults located on the territory of the city can enhance or weaken the effect of passing seismic waves of earthquakes with foci in other seismogenic zones outside the city.

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During last 15 years, the appearance of earthquake foci has been noted on the territory of the city, the seismic effect of which has so far been noted within 2-3 points. In the city of Almaty, there are 10 engineering seismometric stations on buildings, which also recorded earthquakes with foci in the city. The stations are equipped with digital and analogue systems. Each building is essentially a pendulum system.

## 2 Materials and methods

On May 1, 2011 at 08:31 am, a tangible earthquake occurred in the vicinity of Kapshagai. Its intensity in the territory of Almaty was 4-5 points. Magnitude  $M_B=5,3$ ,  $M_S=4,8$ ,  $M_W=5,4$ ,  $mpv=5,9$ ,  $K=13,1$ . However, due to subjective reasons, instrumental recordings were not received at station 1.

According to the operational data of the Data Center of the Republican State Enterprise 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), 31 km southeast of Kapshagai, 63 km to an earthquake occurred to the north-east 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 points and much stronger in the city of Kapshagai.

Instrumental data were obtained by the stations of the engineering and seismometric service of KazRDICA JSC. It is of interest to compare instrumental recordings on rigid and flexible buildings.

The rigid building is a 4-storey brick-framed building, while the flexible building is an 11-storey steel-framed building. It should be noted that the 11-storey building is located between two tectonic faults, from which it is 1-1.5 km away.

The research methods are experimental, based on the analysis of experimental records of the engineering and seismometric service stations on buildings.

## 3 Results

### 3.1 Rigid building

Seismic station No. 1 is located in the southern part of the city at the intersection of Gagarin and Dzhandosov streets.

Seismic station No. 1 "Institute" is mounted in a 4-storey L-shaped frame building. The frame is made of reinforced concrete. Ground conditions- boulder-gravel. The station was installed in 1968. This is historically the first station of the engineering and seismometric service in Almaty. The devices are located in the basement on the foundation and on the roof of the building. It was modernized in 2008. Currently, the seismic station is equipped with both analog sensors OSP (seismic receiver) and VBP (vibrographs), and a digital instrumentation and measuring system RSM-8 [3, 4].

Figures 1-2 show the accelerations distribution in the horizontal plane both at the basement level and at the roof level. At the basement level, the maximum acceleration value is  $10, 23 \text{ cm} / \text{s}^2$ , and in the roof -  $41.75 \text{ cm} / \text{s}^2$ . This is 11-23% higher than the acceleration values from Table 1.

Figures 2-5 show instrumental records (accelerograms) at the roof and basement levels. The spectral curves at the oscillation decrement 0.3 are shown in Figures 6-7.

Table 1 shows the results of measurements and calculations ( $h$  is the sampling step of accelerograms).

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

Component	Acceleration, $cm/s^2$	Effective duration, s	Spectral coefficient	Spectrum maximum period, s
27.03.18-1-0-u1, roof level OX	32.08	23.65	8.23	0.46
27.03.18-1-0-u2, roof level OY	30.38	11.35	4.60	0.42
27.03.18-1-0-u3, roof level OZ	9.30	16.70	6.51	0.10
27.03.18-1-0-u6, basement level OX	7.21	6.29	3.13	0.16
27.03.18-1-0-u7, basement level OY	9.62	5.17	2.77	0.21
27.03.18-1-0-u8, basement level OZ	3.29	13.97	3.72	0.21

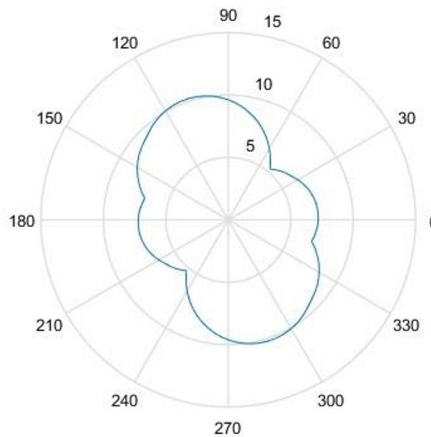
The current scale MSK-64 (K) is compiled for earthquakes with an intensity of 5-10 points. This earthquake does not fall within the specified interval in terms of the values of the registered accelerations. The indicated scale contains accelerations from  $16 \text{ cm/s}^2$  to more than  $900 \text{ cm/s}^2$ . Here the acceleration in the basement level in the azimuthal plane is  $7-9 \text{ cm/s}^2$ .

Therefore, it is fair to attribute the earthquake of 03/26/2018 to a seismic event with an intensity of 4 points on the territory of Almaty in the area of seismic station No. 1 "Institute".

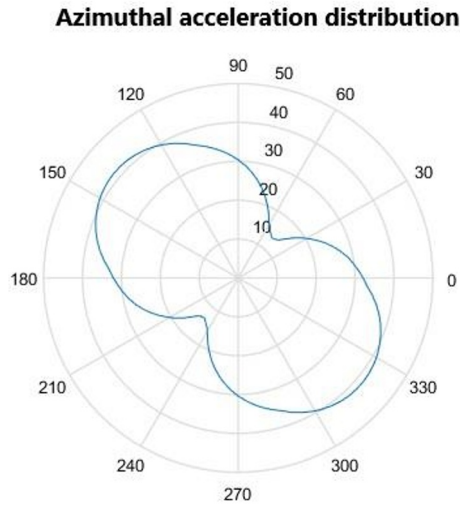
The accelerations at the roof level are approximately 4 times higher than the accelerations at the basement level for all components.

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 0.16-0.21 s.

**Azimuthal acceleration distribution**



**Fig. 1.** Azimuthal acceleration distribution at the basement level.

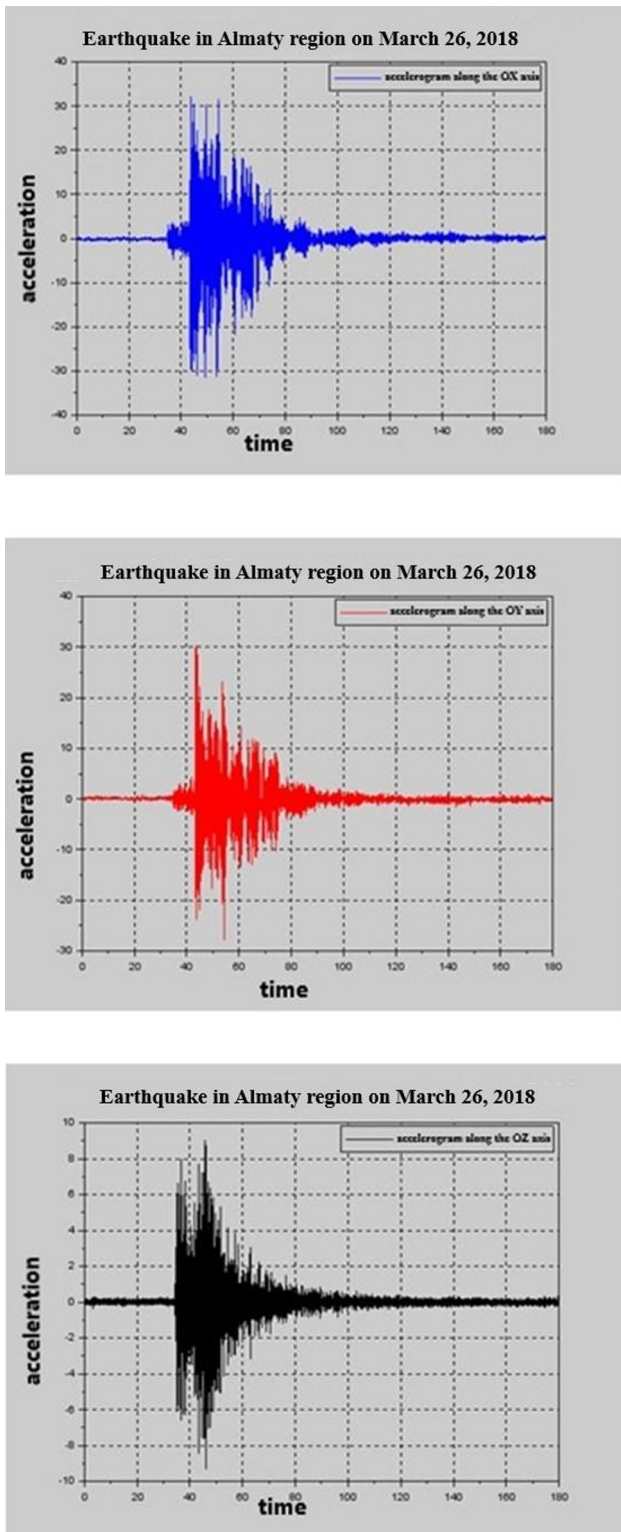


**Fig. 2.** Azimuthal acceleration distribution at the roof level.

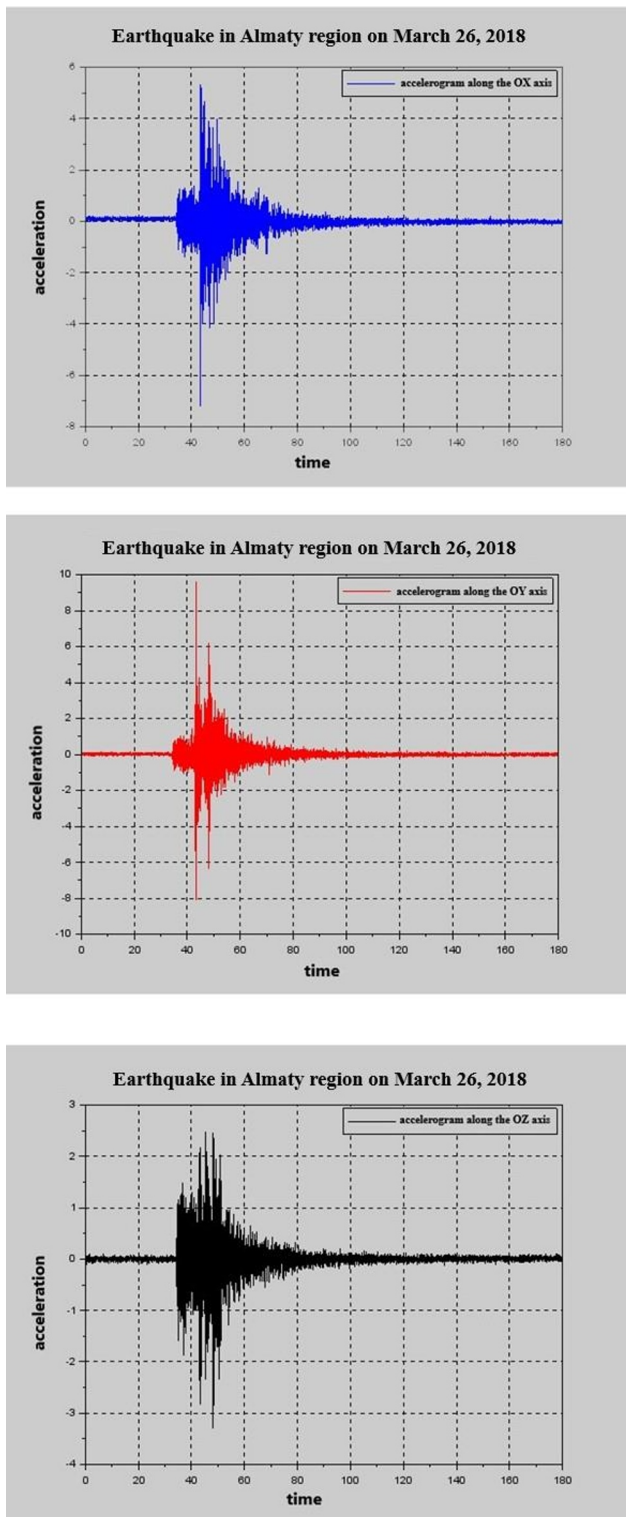
A two-component instrumental recording of an earthquake in the horizontal plane is a decomposition of the seismic impact along two orthogonal axes oriented along the parts of the world or in some other direction (for example, along the side of a building).

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 you can get a new coordinate system in which the projections of the acceleration vector can have other, very different, parameters. Consequently, the dynamic effect of an earthquake also differs depending on the orientation of the coordinate system.

The distribution of accelerations along the height of buildings is classical with an increase in the values of acceleration along the height of the building. Apparently, there are resonant vibrations of the object.



**Fig. 3.** Instrumental records (accelerograms) at the roof level (seismic station No. 1).



**Fig. 4.** Instrumental records (accelerograms) at the basement level (seismic station No. 1).

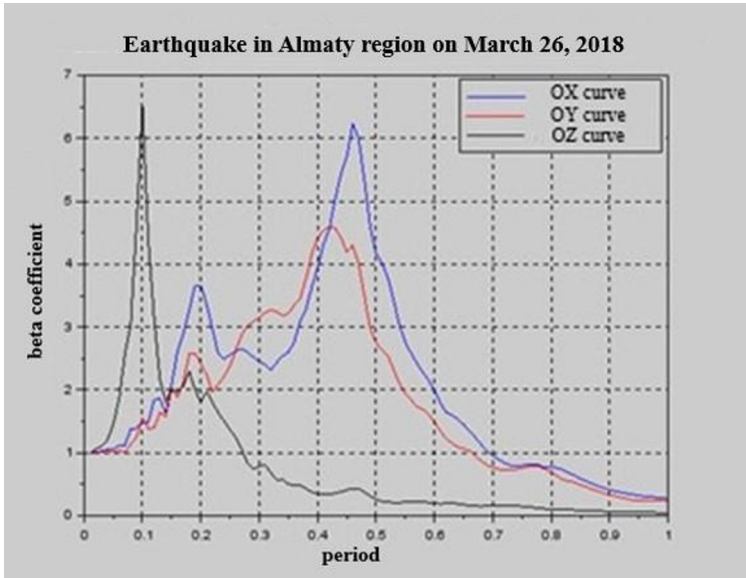


Fig. 5. Spectral curves at the roof level (seismic station No. 1).

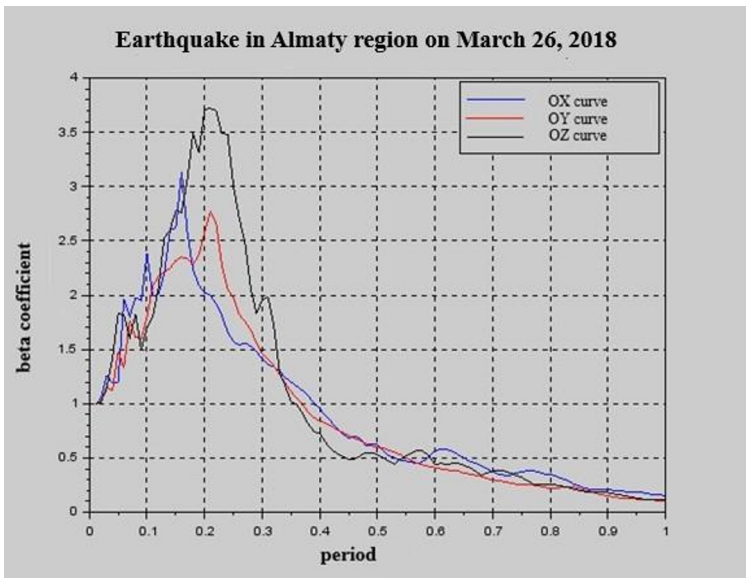


Fig. 6. Spectral curves at the basement level (seismic station No. 1).

### 3.2 Flexible building

Station No. 11 "Prospect Abay" is located on an 11-storey office building made in a metal frame. It is worth noting that this station is one of the very first in Almaty - it began operating in 1970. In 2010, the first modernization of the station took place - a digital instrumentation and measuring system was installed. The second upgrade was carried out in 2016 - the ADXL accelerometers were replaced by the AT 1105. The soils are boulder-gravel. The building has dimensions 15×36 m, height 43.6 m. From a constructive point of view, the building is frame-panel. External wall panels made of aluminum with glass and

stemolite filling. The frame consists of longitudinal and transverse closed frames with a transverse and longitudinal column pitch of 6 m. The height of the basement is 3.4 m, the first floor is 4.2 m and all subsequent ones are 3.6 m (Table 2).

Foundations are concrete banded. The basement walls are made of monolithic concrete. The columns of the frame are anchored to the walls of the basement with the help of metal shoes. Ceilings over the first and basement floors are made of monolithic reinforced concrete; over the rest of the floors, the ceilings are made of prefabricated reinforced concrete ribbed slabs of 3 - 6 m in size. The partitions are made of prefabricated expanded clay concrete panels, as well as from precast gypsum concrete and slag concrete slabs.

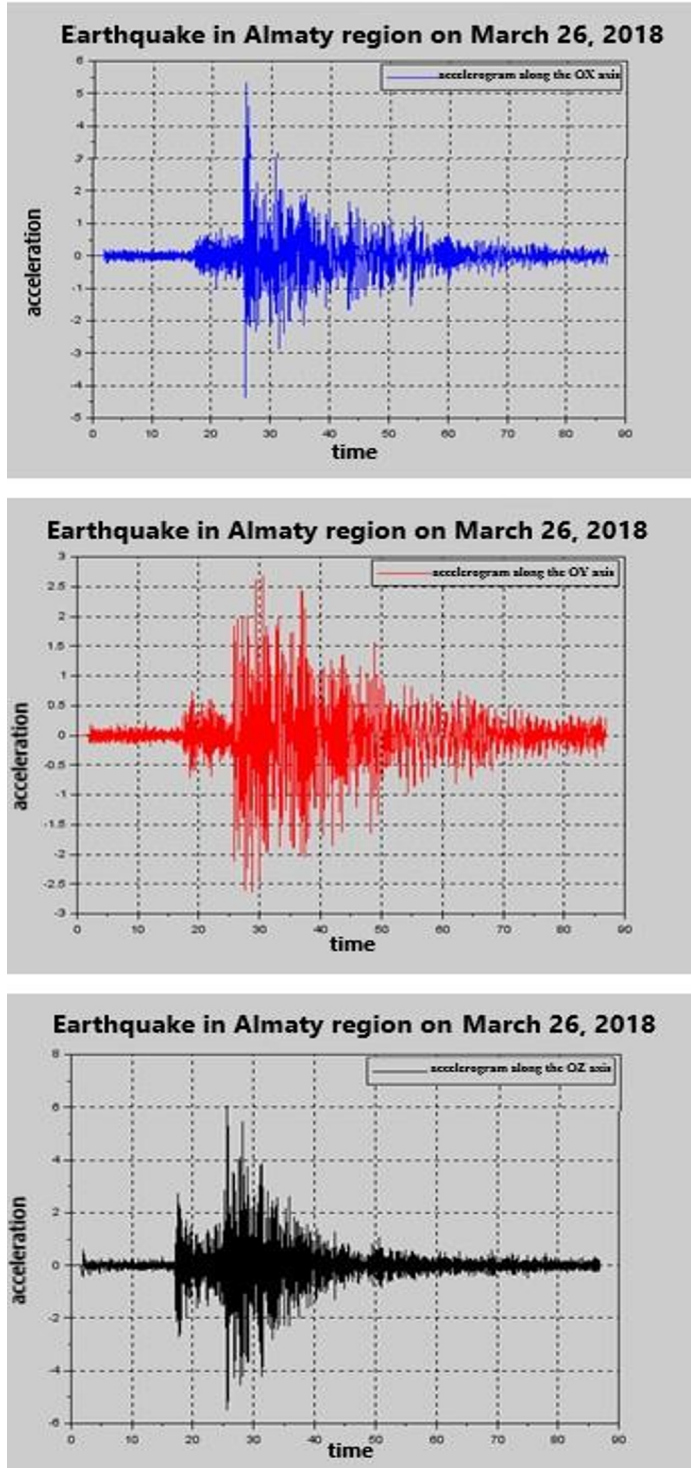
At the top of the building there is a technical floor (12th floor), where part of the control and measuring equipment is located - the upper registration point (mark 40.2 m). The bottom check-in point is located in the basement. The devices are located at the -4.4m mark (the basement itself is at the -3.4m mark). Earlier, instrumental records (accelerograms) were obtained on this building during the earthquake of August 9, 2017 in China (Xinjiang Uygur Autonomous Region).

**Table 2.** Maximum values of accelerations and parameters of accelerograms during the earthquake of March 26, 2018 ( $h = 0.0064s$ ).

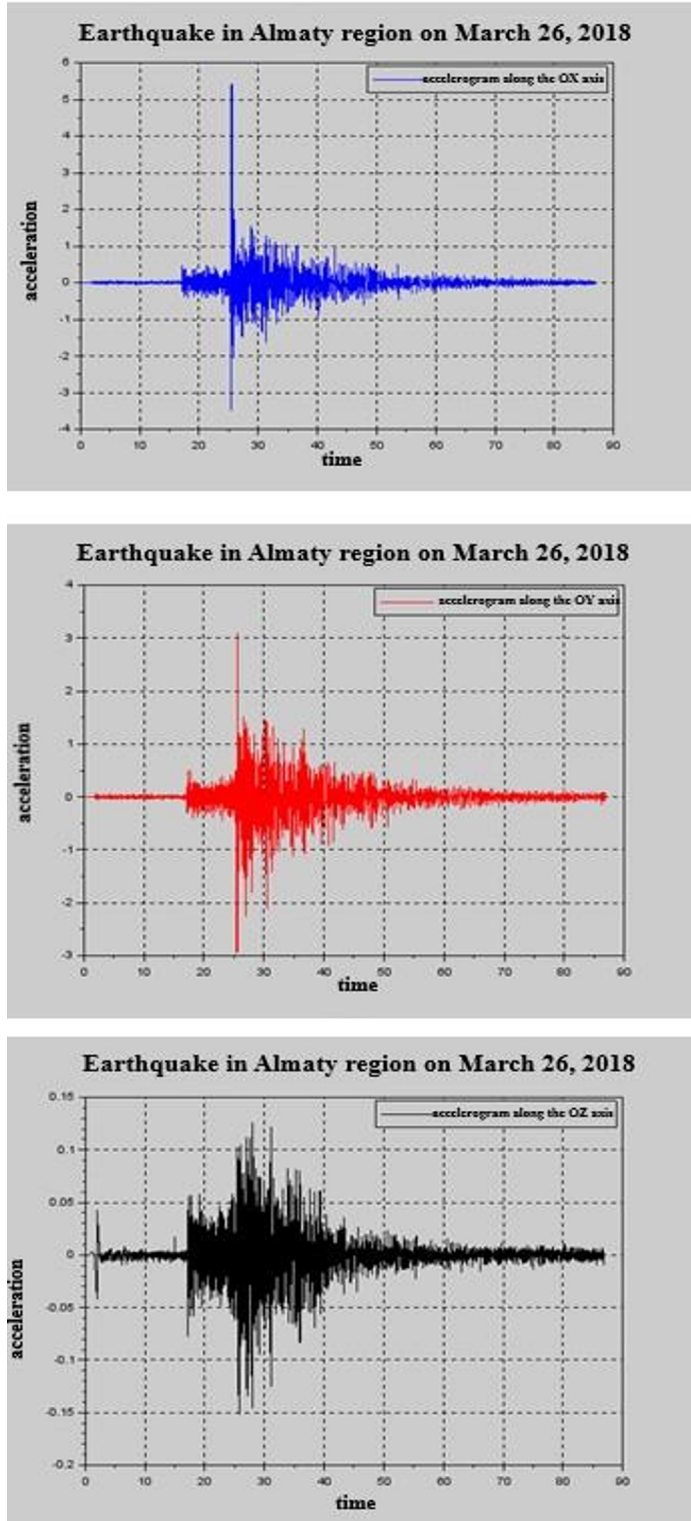
Component	Acceleration, $cm/s^2$	Effective duration, s	Spectral coefficient	Spectrum maximum period, s
27.03.18-11-7-u1, roof level OX	5.33	5.88	3.09	0.19
27.03.18-11-7-u2, roof level OY	2.69	23.08	5.53	0.23
27.03.18-11-7-u3, roof level OZ	6.09	5.89	4.74	0.14
27.03.18-11-7-u6, basement level OX	5.44	0.12	2.60	0.17
27.03.18-11-7-u7, basement level OY	3.06	5.09	3.06	0.17
27.03.18-11-7-u8, basement level OZ	0.15	18.73	4.27	0.22

Figures 7-8 show the recorded accelerograms at the roof and basement levels. Figures 9-10 show the corresponding spectral curves

Here the acceleration at the basement level in the azimuthal plane is 5.44-3.08  $cm/s^2$ . Therefore, here the intensity of the earthquake on 03/26/2018 is approximately 3 points in the area of seismic station No. 11 "Prospect Abai". Compared to the rigid building of the Institute seismic station, the acceleration values in the azimuthal plane at the roof level do not exceed the acceleration values in the basement of the building. The effective durations of accelerograms vary here within wide limits. The periods of the spectrum maximum at the basement level in the azimuthal plane are 0.17 s. The building does not vibrate with resonance. The vibrations of the building are in the nature of vibrations. Acceleration in the level of the last tier is about 6 times less than in a rigid building.



**Fig. 7.** Instrumental records (accelerograms) at the roof level (seismic station No. 11).



**Fig. 8.** Instrumental records (accelerograms) at the basement level (seismic station No. 11).

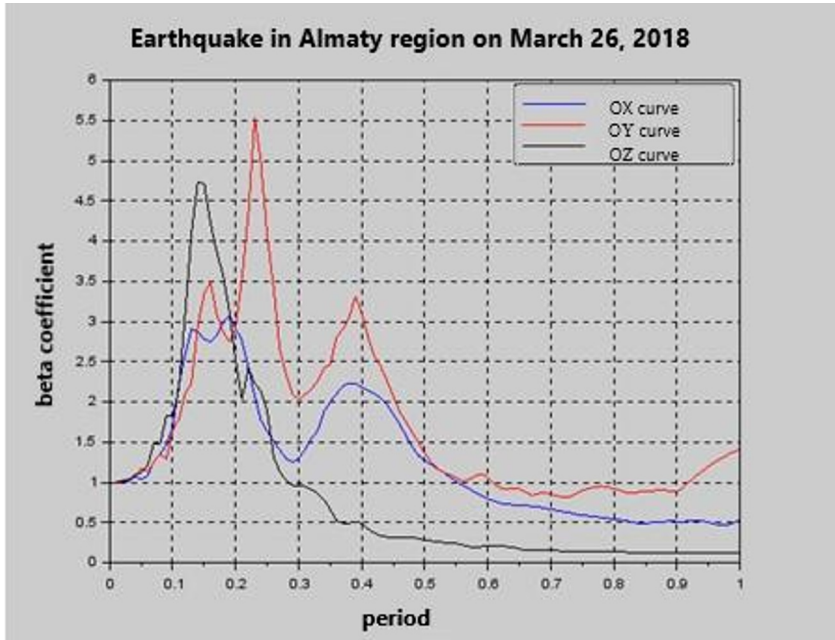


Fig. 9. Spectral curves at the roof level (seismic station No. 11).

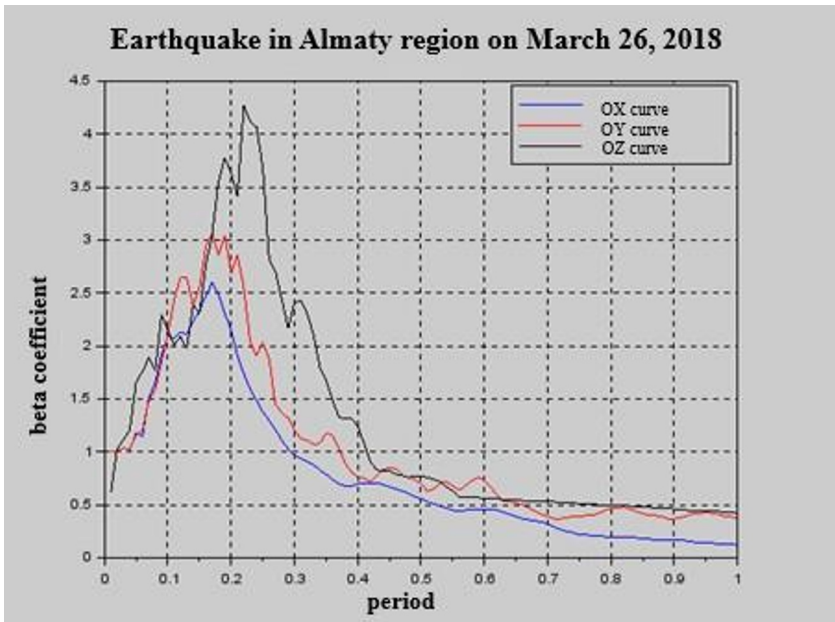
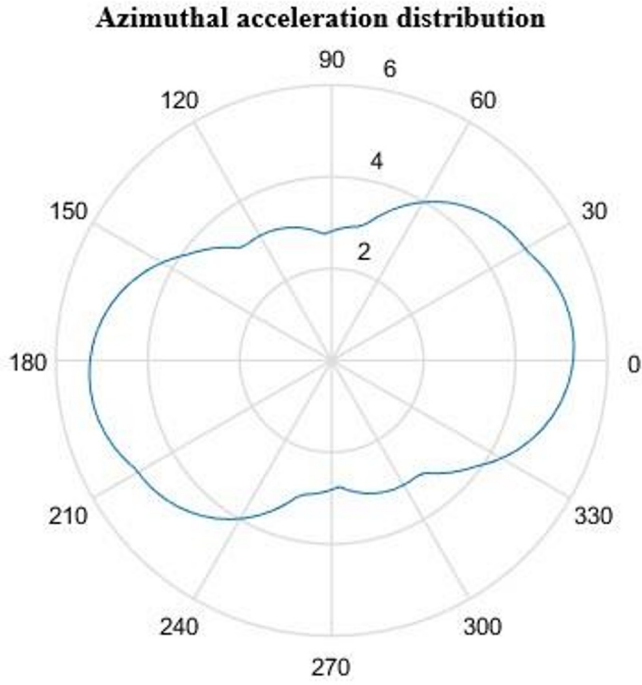


Fig. 10. Spectral curves at the basement level (seismic station No. 11).

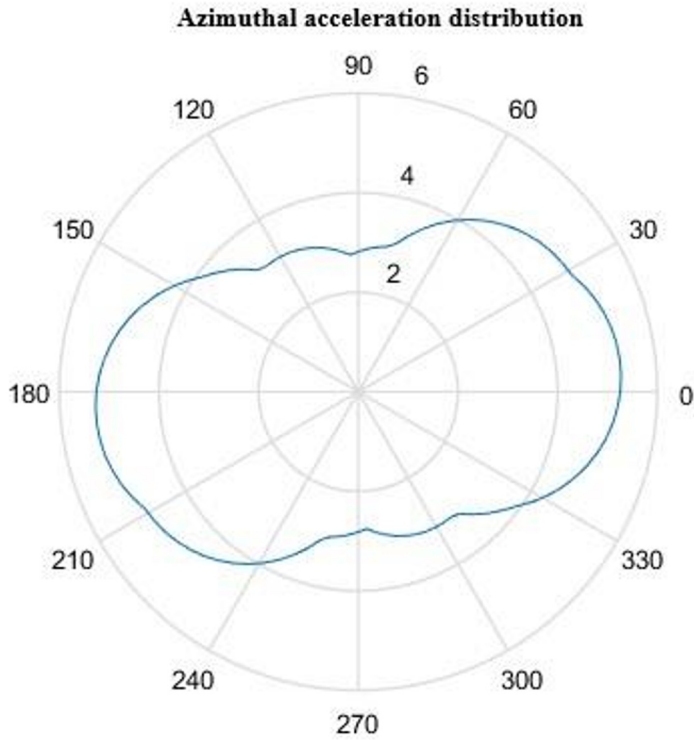
## 4 Discussion

Figures 11-12 show the accelerations distribution in the horizontal plane at the basement level and the level of the roof of an 11-storey building. At the basement level, the maximum acceleration value at the basement level is 6, 15 cm/s<sup>2</sup>, the roof - 5.35 cm/s<sup>2</sup>. This

is 11% and more percent higher than the acceleration values from Table 2. The azimuthal acceleration distribution plane is smoother.

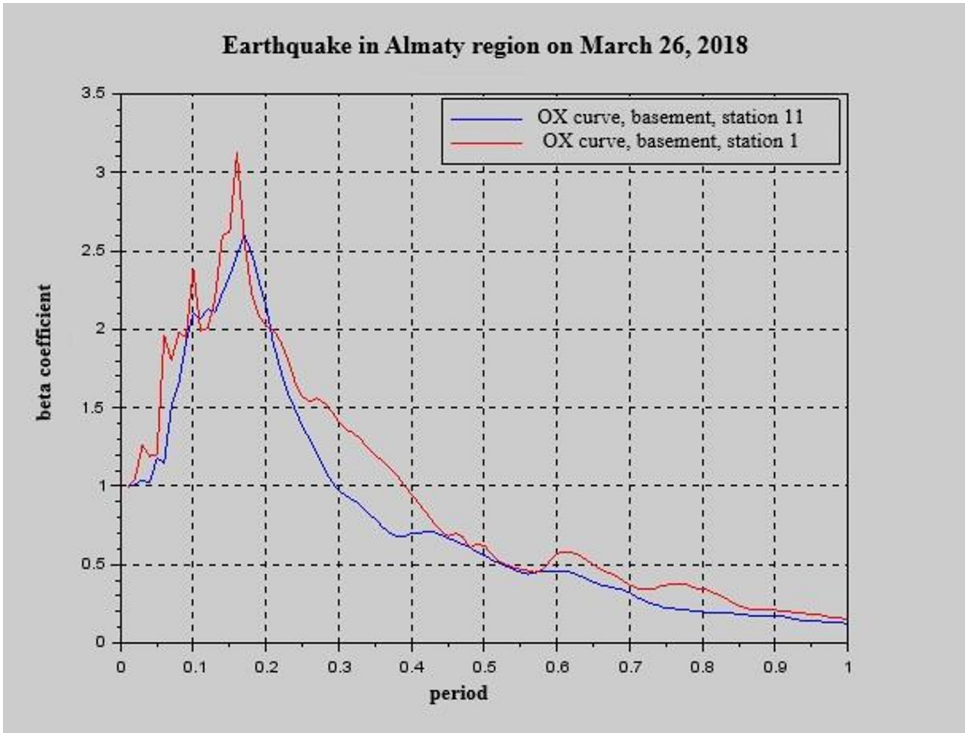


**Fig. 11.** Azimuthal acceleration distribution at the basement level.

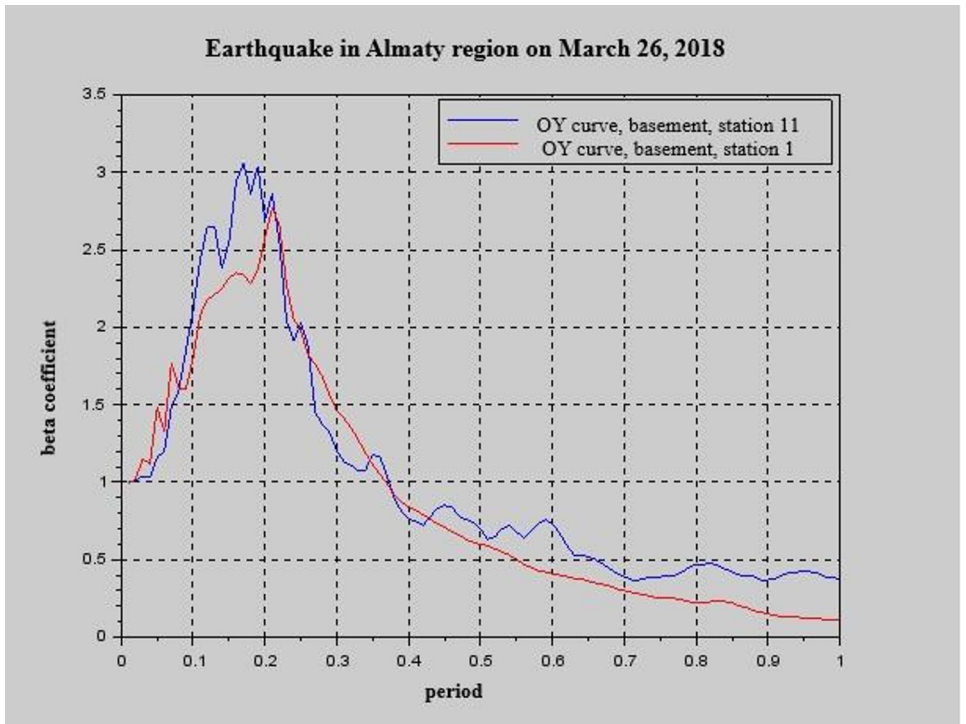


**Fig. 12.** Azimuthal acceleration distribution at the roof level.

In Figures 13-14, spectral curves are grouped along the axes in the basement level of each building. Let's underline, the ground conditions are the same – boulder-gravel. The spectral curves characterizing the dynamic effect of seismic action practically coincide. It is interesting to note that no tectonic fault was observed near the rigid building. The flexible building is approximately 800 m away from tectonic faults on both sides of the house. Since the spectral curves coincide, it can be concluded that the influence of tectonic faults is not manifested here. This is an important conclusion for assessing the impact of tectonic faults on the response of buildings and structures.



**Fig. 13.** Spectral curves, basement along the OX axis.



**Fig. 14.** Spectral curves, basement along the OY axis.

It should be noted that 2 buildings with seismic stations No. 1 and No. 11 form a sample convenient for studying the spectral composition of the impact. These are, in a sense, 2 classical pendulums with quite different periods of oscillation along the fundamental tone.

It is advisable to modernize the stations using the latest instrumentation and measuring systems [5-9]. Note that it is advisable to equip buildings with new constructive solutions with seismic stations, including objects at sites with unfavorable soil conditions, as well as buildings equipped with seismic isolation systems [10-17].

## 5 Conclusions

1. Periods of the maximum spectrum for instrumental records at the level of the last tier of a rigid building (seismic station No. 1) characterize the period of oscillation of the building according to the fundamental tone, taking into account the flexibility of the foundation.

2. The period of the spectrum maximum at the basement or first floor level more characterizes the spectral composition of the seismic impact than the frequency characteristics of the building.

3. For flexible and rigid buildings, the prevailing oscillation periods of the base are approximately the same 0.17-0.21 sec. Note here that the soil conditions are also the same – boulder-gravel. It was found that the spectral curves are very similar in shape. The influence of tectonic faults on the response of an 11-storey building to this earthquake has not been established. Instrumental observations should be continued. A new result was obtained that not every earthquake shows the effect of tectonic faults.

4. The seismic event on March 26, 2018 is an earthquake with an intensity of no more than 3-4 points in the territory of Almaty. The source of the earthquake is located on the territory of the Almaty region near the city of Kapshagai.

5. The accelerograms given in the article will replenish the database of accelerograms of KazRDICA JSC.

6. The above 2 buildings form a sample of rigid and flexible buildings, methodologically convenient for studying the spectral composition of the impact. It is, in a sense, 2 pendulums with quite different periods of oscillation along the fundamental tone.

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