New Tasks Solved by Means of Instrumental Records of Stations of Engineering Seismometric on Buildings Service

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Abstract. New tasks that can be solved using the network of stations of the engineering-seismometric service of JSC KazRDICA consisting of 12 stations on located on rooftops of buildings are considered. Depending on the type of tasks being solved, all stations are divided into groups (test sites). Buildings located tectonic faults were collected in separate group. Buildings on one of the sites are equipped with seismic protection systems and a house analogue. The tools for processing instrumental records are analyzed - adjusting the zero line of the accelerogram by the type of correlation function and building the distribution of accelerations on the azimuthal plane. The possibilities of processing instrumental records for a years-long registration interval are analyzed. Focal points of the earthquake in the city have been identified. A criterion is obtained for assessing the influence of a tectonic fault on the reaction of a building. Recommendations are given on the further development of the engineering seismometric service of JSC KazRDICA. The results are of theoretical and practical value.

1. Introduction

There are few tools that are simple but very useful for exploring buildings and structures located in seismic areas. Engineering seismometric service stations on buildings can be considered as such tools. The instrumental information delivered by them concerns both the features of the deformation of buildings during an earthquake, and the patterns of vibration of the base of the structure. The use of such information seriously reduces losses (reduces risks) in case of possible earthquakes.

The first station of engineering-seismometric service in Almaty was created in 1967 [1]. The first instrumental record was received on December 22, 1967. The station was equipped with analog accelerometers and seismographs. In the following decades the network of stations developed rapidly, and by the 1990s there were 24 stations.

The engineering seismic service (hereinafter referred to as 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. Below are the locations of stations, types of buildings and equipment, as well as the ground conditions of the place of registration (Table 1). At four of stations, both digital and analogue equipment are installed.

Subsequent studies made it possible to solve interesting problems of the theory of earthquake resistance using new methods of structural dynamics [1-6]. At the stations, old analog devices prevail. These are VBP sensors that measure speeds and displacements, and OSP sensors that record accelerations and speeds. There are also SM-4 sensors that
record displacements. Currently, the instrument base is very developed [7-12]. Therefore, the modernization of the stations can be carried out.

Table 1. List of engineering seismometric stations in service.

| №  | Station number and name | Station address and year of foundation | Structural design of the building | Station type |
|----|------------------------|----------------------------------------|----------------------------------|--------------|
| 1  | Station 1 «INSTITUT»   | Gagarina Ave., corner st. Dzhandosova, 1968 | 4-storey frame building / boulder-pebble | Analog + |
| 2  | Station 3 «SHKOLA»     | Raiymbek Ave., corner of Abylay Khan Ave., 1969 | 4-storey frame / reinforced concrete / pebble with sand and clay layers | Analog |
| 3  | Station 7 «TULEPBAYE VA» | st. Tulebaev, corner of st. Kazybek Bi, 1974 | 9-storey frame / reinforced concrete / SZhKU-9 / boulder-pebble | Analog |
| 4  | Station 11 «PR. ABAYA» | Abay Ave., corner of st. Furmanova, 1970 | 11-storey frame / steel / boulder-pebble | Analog + |
| 5  | Station 15 «KAPSHAGAI» | Kapshagay city, Kapshagai hydroelectric station, 1975 | 1-story frame industrial building / steel / dams: bulk 30 m and 40 m high. / Fissured ledge rock | Analog |
| 6  | Station 16 «VISOTNAYA GOSTINICA» | Dostyk Ave., Abay Ave., “Kazakhstan” Hotel, 1977 | 25-storey hotel / spatial system formed from an ellipsoid trunk with diaphragms diverging in the vertical plane / boulder-pebble with sand filling | Digital RSM-16 |
| 7  | Station 17 «NOVAYA PLOSCHAD» | st. Bayseitova, Republic Square, 1987 | Rigid core 17-story residential building / dense boulder-pebble | Analog + |
| 8  | Station 20 «DOM – ANALOG» | st. Rozybakieva, 25, 1989 | 9-storey large-panel building of the 158 series / system of cross tapes foundations / boulder-pebble | Analog |
| 9  | Station 21 «DOM – KF» | st. Rozybakieva, 33, 1989 | 9-9-storey large-panel building of the 158 series / kinematic foundations / boulder-pebble | Analog |
| 10 | Station 22 «DOM – FT» | st. Rozybakieva, 41, 1989 | 9-story large-panel building of the 158 series with seismic isolation of supports with fluoroplastic gaskets / boulder-pebble | Analog |
| 11 | Station 23 «TARZ – FILIAL» | Taraz city, st. Suleymanova 19b, 2004 | 3-story brick building | Analog |
| 12 | Station 24 «UCHEBNYI CENTER» | st. Mynbaeva, 53, 2008 | 3-story frame building / boulder-pebble | Analog |
The engineering – seismometric service (ESS) solves the following classical main tasks:

1. Obtaining the actual (experimental) instrumental data on the dynamic parameters and stress state of the supporting structures of buildings in different soil conditions;
2. Assessment of the accumulation of damage in load-bearing structures and specification of reserves of the bearing capacity of buildings after seismic impact (earthquake);
3. Accumulation of a database of instrumental engineering – seismometric earthquake records used for:
   – refinement of the microseismic zoning map of the territory regarding the influence of soil conditions on the reaction of the building; clarification of the location of tectonic faults;
   – clarification of the occurring seismic loads on buildings and structures during real earthquakes. For example, converted records of ESS stations were used in the calculation of buildings with active seismic protection systems;
   – construction of spectral curves and regional accelerograms taking into account local features of seismic impact. This is a new task of great practical importance.

The purpose of this work is to indicate new tasks that are solved using instrumental records of the engineering-seismometric service of JSC KazRDICA, Almaty, the Republic of Kazakhstan. The obtained new research methods and results are analyzed.

Instrumental records are experimental information on the behavior of buildings during an earthquake.

2. New tasks
The network of stations (table 1) is divided into a set of test sites that solve certain tasks (table 2).

| №  | Task to be solved                                                                 | Stations                  | Notes                          |
|----|-----------------------------------------------------------------------------------|---------------------------|--------------------------------|
| 1  | Evaluation of the effectiveness of seismic isolation systems                        | №20 «DOM – ANALOG», №21 «DOM – KF», №22 «DOM – FT» | New task: seismic isolation testing ground |
| 2  | Accumulation of a database of instrumental engineering-seismometric earthquake records | All stations             | Classic task                  |
| 3  | Assessment of the influence of tectonic fault on the reaction of the building       | №16 «VISOTNAYA GOSTINICA», №17 «NOVAYA PLOSCHAD» | New task: assessing the impact of tectonic faults on the territory of the city on the buildings |
| 4  | Assessment of the influence of soil conditions on the seismic impact and the reaction of the building | All stations             | Classic task                  |
| 5  | Construction of spectral curves and regional accelerograms taking into account local features of seismic effects | All stations             | New task: for the cities of Almaty, Taraz and Kapshagay |
| 6  | Assessment of the influence of the operating life on the change in the dynamic characteristics of a building | №16 «VISOTNAYA GOSTINICA» | New task                      |
| №  | Task to be solved                                           | Stations                                                                 | Notes  |
|----|------------------------------------------------------------|--------------------------------------------------------------------------|--------|
| 7  | Determination of wave speed by building height            | №16 «VISOTNAYA GOSTINICA»                                               | Classic task |
| 8  | Identification of dynamic systems modeling a building     | №1 «INSTITUT», №11 «PR. ABAYA», №16 «VISOTNAYA GOSTINICA» №17 «NOVAYA PLOSCHAD» | Classic task |
| 9  | A set of pendulum systems for determining the frequency composition of an earthquake | №1 «INSTITUT», №11 «PR. ABAYA»                                           | Classic task |
| 10 | Assessment of the impact of water hammer on the seismic resistance of a bulk dam | №15 «KAPSHAGAI»                                                          | New task |

2.1. Assessment of the influence of tectonic faults

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), 31 km southeast of Kapshagai, 63 km north-east An earthquake occurred east of Almaty. Epicenter coordinates: N 43° 42' 0", E 77° 21' 36". Magnitude mpv = 5. Energy class K = 11.4. Depth h = 7 km. An earthquake was felt in the city of Almaty with an intensity of 3 points and much stronger in the city of Kapshagai.

Figures 1-2 show spectral curves grouped along the axes at the basement level of a flexible and rigid building. We emphasize that the ground conditions are the same - a boulder-pebble. The spectral curves characterizing the dynamic effect of seismic effects are almost identical. It is interesting to note that no tectonic fault was observed near the rigid building. The flexible building is approximately 800 m from the tectonic faults on both sides of the house. Since the spectral curves coincide, we can conclude that the influence of tectonic faults does not appear here.

With a high degree of certainty, it can be argued that differences or coincidence of spectral curves is a measure of the impact of tectonic faults on the reaction of a building.

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

![Figure 1. Spectral curves, Basement on OX axis](image1)

![Figure 2. Spectral curves, Basement on OY axis](image2)
2.2. The new task of processing accelerograms
Fifty years of experience in operating ESS stations and processing instrumental records was the reason for the development of various methods for analyzing earthquake accelerograms.

Until now, most of the stations are equipped with analog recording equipment. Instrumental recordings are recorded on photo paper. The next step is to digitize the analog recordings. It can be manual, machine, using scanning systems or specially designed programs. But all will have a certain error due to both objective and subjective reasons.

Therefore, it is worth considering a possible way to adjust the zero line of the instrumental record.

Figure 3 shows a sample of an instrumental record (accelerogram) with a slight subtle deviation from the zero line (accelerogram of the Bakanas earthquake on September 25, 1979, «TULEPBAYEVA» station №7, M = 5.8, H = 35 km, D = 158 km, sampling step 0.025 sec). However, the correlation function of the accelerogram is very strongly deviated from the zero line, which practically excludes its approximation and use (Fig. 4).

The automatic shift of the zero line of the accelerogram (correction) was accompanied by a recalculation of the correlation function. Figure 5 shows the correlation function after adjusting the zero line. The correlation function is practically located on the axis of the delay time, intersecting it in length.

In this case, the maximum acceleration value at the initial accelerogram has changed very little from 4.4 cm/s² to 4.0 cm/s².

![Figure 3. Accelerogram of the Bakanas earthquake, September 25, 1978](image)

![Figure 4. Correlation function of the Bakanas earthquake, September 25, 1978](image)
Thus, a new method for correcting the zero line by the method of recalculating the correlation function is proposed.

2.3. Construction of the distribution of acceleration on the azimuthal plane

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

Therefore, the impact parameters: maximum or rms accelerations, frequency composition (visible or prevailing periods) are studied from the projections of seismic effects on these axes. Consequently, the information on the exposure parameters obtained in this way is to some 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 varies depending on the orientation of the coordinate system.

Taking $\tilde{X}, \tilde{Y}$ as the projection of the acceleration vector $\tilde{r}$ at time $t$, we define $\dot{X}, \dot{Y}$ in the new axes formed by rotation of the coordinate system by an angle $\phi$:

$$
\dot{X} = \tilde{X} \cos \phi + \tilde{Y} \sin \phi
$$
$$
\dot{Y} = -\tilde{X} \sin \phi + \tilde{Y} \cos \phi
$$

According to formulas (1), projections of $\tilde{r}$ in new axes are determined, that is, instrumental records are recalculated in new axes. Naturally, in the accelerograms thus obtained, their characteristics change - the period of the spectrum maximum, effective duration, etc.

As an example, let us consider instrumental records recorded at the seismic station №17 «NOVAYA PLOSCHAD», during the earthquake of March 26, 2018 in Almaty, attributed to a seismic event with an intensity of 4 points.

Figures 6-7 show the distribution of accelerations in the horizontal plane, both at the level of the 10th floor and at the level of the roof. Angle pitch $2\pi / 50$. 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 $14.26 \text{ cm/s}^2$, the roof - $9.83 \text{ cm/s}^2$.

The distribution of accelerations in Fig. 6 is fairly standard.

The distribution of acceleration in the horizontal plane at the level of the technical floor has a very uneven appearance (Fig. 7) - it resembles the “eight”. Such a distribution occurs when the acceleration value is close to zero on one of the orthogonal axes, and almost the maximum value on the other.
3. The stability of the main spectral characteristics of earthquakes. Results

It is clear that for each accelerogram it is possible to construct spectral curves that will characterize the dynamic effect in the indicated direction [2].

Here is the time to consider the construction of spectral curves. The most common way is to use the Voigt model, which describes the oscillations of a single-mass elastic system with energy dissipation to overcome viscous friction - as it was customary to say, the Voigt body with a parallel connection of elastic and viscous elements. This method is the most common and numerous bibliography is devoted to it.

Therefore, for the analysis of instrumental records of engineering-seismometric service stations, it is most convenient to use the classical Voigt model, which explicitly depends on two parameters — the vibration decrement $\delta$ and the period of oscillation of the elastic system $T$:

$$\ddot{x} + 2\frac{\delta}{T} \dot{x} + \left(\frac{2\pi}{T}\right)^2 x = -\ddot{x}_0 . \quad (2)$$

The principle of continuity of observation is fundamental when conducting engineering-seismometric observations. Even old analog instruments deliver instrumental records of earthquakes. Digitizing such records is not easy enough. However, this is not a reason to get rid of obsolete analog accelerometers.

Figure 8 shows the spectral curves of the accelerograms obtained during the earthquakes of March 23, 1978 and March 26, 2018 at the «Kapshagayskaya» hydroelectric power station [4].

The time interval between the indicated earthquakes is 40 years.

The analysis shows that, due to differences in the parameters of earthquake sources, the spectral curves do not coincide. However, in the high-frequency region, the maximum values of the spectral coefficient differ by no more than 10%, and the periods of the maximum of the spectrum by 20%, which is a characteristic of the spectral composition at a given recording point.

The above principles for creating and processing instrumental earthquake records will be used to create a network of stations in the cities of Ust-Kamenogorsk, Shymkent, Taldykorgan and Turkestan.
Figure 8. Comparison of the spectral curves of two earthquakes, March 23, 1978 and March 26, 2018

4. Conclusions
1. The network of engineering-seismometric service stations on the buildings of JSC KazRDICA is an effective provider of information on the behavior of buildings and structures in real seismic conditions.

2. A new method has been developed for correcting the zero line of the accelerogram by its correlation function, which may be useful for mass processing of instrumental records received by ESS stations.

3. Instrumental information is used both when adjusting regulatory and technical documents in construction, and when conducting direct dynamic calculations of buildings and structures, including seismic isolation systems [13,14].

4. ESS stations are indispensable in studying the behavior of buildings near tectonic faults. On the territory of the city of Almaty, two stations are installed on buildings located near tectonic faults. The distance to the alleged edge of the fault is measured in tens of meters. These stations are unique regular suppliers of instrumental information on the impact of faults on the behavior of buildings and their foundations during earthquakes.

5. A criterion is proposed for assessing the impact of the tectonic fault on the reaction of the building.

6. In recent years, with the help of ESS stations, the possibility of earthquakes with foci in the territory of Almaty was identified [5]. Therefore, when placing new stations in the city, this factor must also be taken into account.

5. References
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