ASSESSMENT OF POSSIBLE SEISMIC HAZARD AND RISK USING THE EXAMPLE OF ALMATY

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Abstract

In January 2024, residents of Almaty felt the seismic impact of an earthquake that occurred on the border of China and Kyrgyzstan. The city was not prepared for such an event. How could the city residents prepare for this devastating earthquake? In order to properly prepare the population for a destructive earthquake, it is necessary to have a system for assessing the individual seismic risk of the city, which uses data for risk assessment: on predicted possible earthquake sources (PES) dangerous for the city for the next 10 years, on the seismic resistance of buildings and the city's population. Based on these data, the possible individual risk for the city population is assessed. In order to assess the individual risk as accurately as possible, in addition to data on the PES and seismic resistance of buildings, data on the macroseismic field from the PES forecast are needed. At present, there are all the necessary scientific and technical capabilities for creating monitoring systems for seismic protection of cities.

Keywords: Dynamic-geophysical method, seismic hazard, possible earthquake source, building seismic resistance, individual seismic risk

I. Introduction

Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nam dui ligula, fringilla a, euismod Since 1999, for several years, the Federal State Budgetary Institution All-Russian Research Institute of Civil Defense and Emergencies has been on duty 24 hours a day using the Extremum geographic information system (GIS). The GIS used an original probabilistic model for assessing the consequences of strong earthquakes. The model used a database of seismic resistance of buildings in all countries of the world, including Kazakhstan, data on tectonic faults and data on geology for its calculations. These data are used to construct a macroseismic field [1,2]. The model is based on the probability laws of destruction of buildings of various design depending on seismic impact [3].

Analysis of data on the rescue of people after the impact of a catastrophic earthquake, who were in the rubble of buildings and structures, shows that after 24 hours up to 47% of people in the rubble die, and after 3 days the percentage of fatalities increases to 60%, after 6 days the percentage of fatalities reaches 85%. The graph of the deaths of those trapped in the rubble is shown in Figure 2. Experience in assessing the consequences of catastrophic earthquakes shows that data on the real consequences in populated areas arrive with a significant delay measured in days, while it is important to know as accurately as possible the distribution of victims in the six-point macroseismic field zone of a catastrophic earthquake. The correct distribution of forces and resources provides a gain in time and the opportunity to save the maximum number of survivors.

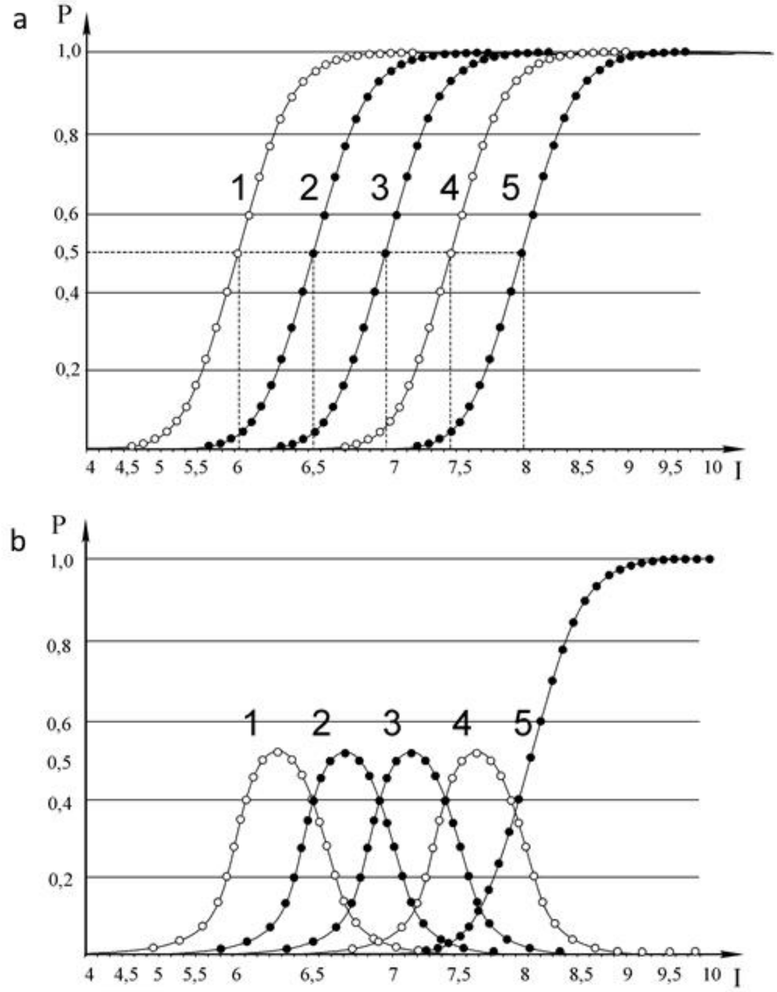

Figure 1: *Example of destruction laws during earthquakes for class A buildings (made of local materials) a — not less than certain degrees of damage; b — certain degrees of damage; 1, 2, 3, 4, 5 — degrees of damage to buildings.*

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Using the GIS "Extremum" it is possible to quickly assess the possible consequences both according to the PES and according to promptly received data on the parameters of seismic events. The calculation of consequences is performed within a time not exceeding 0.1-0.5 hours. Based on the data received, an assessment of the individual risk for the population that fell into the 6-point zone of the territory in the epicentral zone of a catastrophic earthquake is performed.

As can be seen from Table 1, when calculating the consequences for the territories of Asia using the GIS "Extremum", out of 13 cases considered, in 7 cases the calculations of the consequences were 50% or more accurate, in the remaining 5 cases the calculations were erroneous. Errors arose due to incomplete data on development, population, scatter of data on the earthquake source, macroseismic field.

Table 1: *Examples of operational assessment of the consequences of strong earthquakes, carried out using the GIS "Extremum" in 2008.*

№	Date	Time	Longitude	Latitude	Magnitude	Depth km	Place	Irrecoverable losses	Sanitary losses	Fact Irrecoverable losses	Fact Sanitary losses	Convergence, %
1	18.06.2008	08:12:12.5	92,1	33,28	5,5	10	Qinghai, China	0-2	0-3	1	2	100
2	05.08.2008	09:49:15.9	105,59	32,86	6	10	Sichuan, China	12-34	0-38	4	35	100
3	25.08.2008	13:22:00.7	83,59	31,03	6,4	33	Xizan, China	2-11	0-15	> 42	> 30	50
4	27.08.2008	01:35:29.3	104,19	51,63	6,1	10	Lake Baikal, Russia	2139-4528	816-2533	0	0	0
5	10.09.2008	11:00:34.3	55,86	27,01	5,9	15	Southern Iran	16-49	0-61	7	30	50
6	11.09.2008	17:38:59.0	105,72	32,93	5,6	10	Sichuan, China	2-7	0-8	> 3	> 10	80
7	05.10.2008	15:52:49.2	73,75	39,49	6,6	40	Tajikistan-Xinjiang border region	19-75	1-82	> 70	> 50	100
8	05.10.2008	22:56:27.9	69,59	33,97	6	10	Southeast Afghanistan	1590-3396	577-2107	> 60	> 50	10
9	06.10.2008	08:30:43.4	90,48	29,76	6,2	10	Xizan, China	26-63	9-55	0	0	0
10	08.10.2008	14:07:15.2	90,4	29,77	5,6	10	Xizan, China	0-2	0-2	0	0	100
11	13.10.2008	17:16:11.8	70,28	38,67	5,6	33	Afghanistan - Tajikistan, border area	0-1	0-1	>72	>60	1,67
12	28.10.2008	23:09:56.3	67,47	30,74	6,5	15	Pakistan	6093-12589	2529-7185	>1000	>350	16,4
13	29.10.2008	11:32:42.6	67,66	30,68	6,5	15	Pakistan	4838-10088	1958-5802	> 150	> 82	3,1

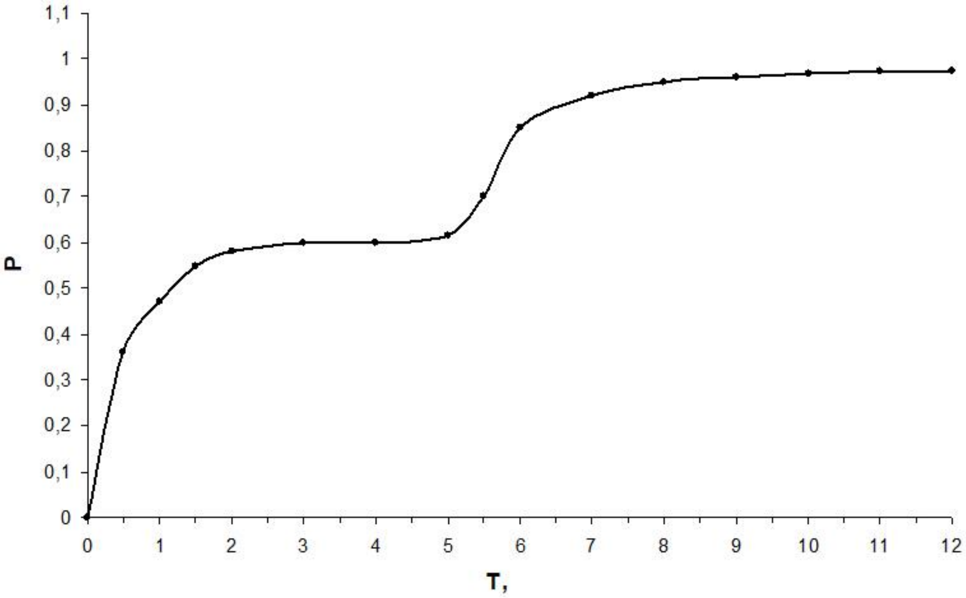

Figure 2: *Dynamics of fatalities among victims trapped in rubble.*

As can be seen from Table 1, when calculating the consequences for the territories of Asia using the GIS "Extremum", out of 13 cases considered, in 7 cases the calculations of the consequences were 50% or more accurate, in the remaining 5 cases the calculations were erroneous. Errors arose due to incomplete data on development, population, scatter of data on the earthquake source, macroseismic field.

To clarify data on seismic resistance of buildings, it is proposed to use mobile diagnostic complexes "Strela-Struna", "Kub", "Tolkyn-1". [2]

For effective planning of measures to protect the population, it is proposed to assess the individual seismic risk at various stages of seismic hazard:

1) when there is a threat of a possible earthquake;
2) when an earthquake occurs (main shock stage);
3) after the earthquake occurs (aftershock stage).

II. Materials and methods

In case of a possible earthquake threat, to calculate the individual risk for the population, it is necessary to have:

1) data on the coordinates and power of possible earthquake sources and the time of their possible triggering;
2) data on tectonics, geology and terrain in the considered possible epicentral 6-point zone;
3) data on the seismic resistance of buildings and structures in the considered zone;
4) macroseismic field from the PES;
5) the population that fell into the 6-point zone of the macroseismic field;
6) the mathematical expectation of population losses in the 6-point zone of the macroseismic field.

How can the parameters of the PES be determined? In the works [5,6,7] it was shown that the PES manifests itself much earlier than the main shock and it manifests itself in a complex manner through mechanical, electromagnetic and hydrometeorological parameters.

The probability of a PES outbreak being triggered can be expressed through the following relationship:

$$P_z = 1 - \prod_{i=1}^{i=n} (\mathbf{1} - \boldsymbol{P_i}) \quad (1)$$

where Pz is the probability of the PES being triggered;
Pi – the probability that the i-th precursor will trigger the PES.

Table 2: *Parameters of precursors and their manifestation in time before earthquakes.*

№	Harbinger type	Time of manifestation before the main shock*	Characteristic types of manifestation of precursors*	Probability of triggering with possible parameters of PES
1	A sharp drop in atmospheric pressure (sharp gusts of wind)	1-20 day	A sharp 72-hour drop and rise in atmospheric pressure to 20 gPa	0,5-5,5 M
		1-7 day	A sharp 12-hour drop and rise in atmospheric pressure to 25 gPa	0,5-5,5 M
2	Manifestation of lightning discharges in a certain sequence	1-7 day	The seismically active region is being fought off	0,3-5,5 M
		4 day	Activity on tectonic faults	0,5-5,5 M
4	Manifestation of a special cloud portrait	1-3 day	Manifestation of linear prorans	0,5-5,5 M
		0,5-7 day	Tectonic faults and the epicenter are reflected linearly	0,7-5,5 M
5	Manifestation of foreshock activity or lull	1-20 day	Tectonic faults or epicenter were repulsed	0,5-5,5 M
		1-20 day May not manifest	Tectonic faults or epicenter were repulsed	0,5-5,5 M
6	Changes in the spectral composition of seismic signals	1-20 day	High frequency noise	0,7-5,5 M
		1-20 day	High and low frequency noises	0,7-5,5 M

*During the process of analysis and observation, the criteria may be refined.

Individual seismic risk is a complex value defined as the quotient of the value of the mathematical expectation of losses in the considered 6-point zone of a possible seismic event for the time during which an earthquake is expected and the number of people in the considered zone.

$$Re_i = P \frac{m_6}{T \times N_6} = [\frac{1}{year}] \quad (2)$$

where: m6 – mathematical expectation of losses in the considered 6-point zone of a possible earthquake, people;

T – the time during which a possible seismic event is predicted, year;

N_6 – the number of people located in the 6-point earthquake zone under consideration;

P - the probability of the PES being triggered during which an earthquake is predicted.

When exposed to an earthquake, it is necessary to immediately after receiving information about the parameters of the seismic event calculate the possible consequences and determine the possible individual risk.

After the impact of the main shock, using forecast data on possible aftershocks and data on the vulnerability of buildings and structures taking into account their damage from repeated impact of seismic events, it is necessary to clarify the possible individual risk. Thus, to calculate the value of individual risk, data on the possible seismic hazard, the seismic resistance of buildings and data on the possible number of people in the zone of dangerous seismic impact are needed.

To assess the activity of the PES, it is proposed to create monitoring networks in the area of probable PES, consisting of sensors, acceleration, speed, displacement, water level sensors in wells, and atmospheric pressure sensors.

The technical parameters of accelerometers installed at seismic stations have a frequency range from 0.5 Hz to 20 Hz and are intended only for timely detection of coordinates of earthquake hypocenters and their power and are not intended for monitoring the technical condition of the soil-structure system. Seismometric soil-structure monitoring systems must include at least four adjacent sensors: one sensor must be located on the ground next to the structure, the second at the base of the structure, the third in the middle part of the structure, and the fourth at the top of the structure. The frequency characteristics of soil-structure monitoring systems must have a range of 0.1-1000 Hz with a sensitivity of 1 V*m/s2. The task of the soil-structure monitoring system is not only to record the parameters of the impact of seismodynamic loads, but also to continuously determine the technical condition of the soil-structure system, its stability and seismic resistance. The studies conducted under the scientific supervision of the author in conditions of real impact of dynamic and seismic loads using multichannel networks provide grounds to conclude that it is possible to create monitoring technologies that ensure timely determination of the technical condition of soil-structure systems, their stability and seismic resistance.

III. Results

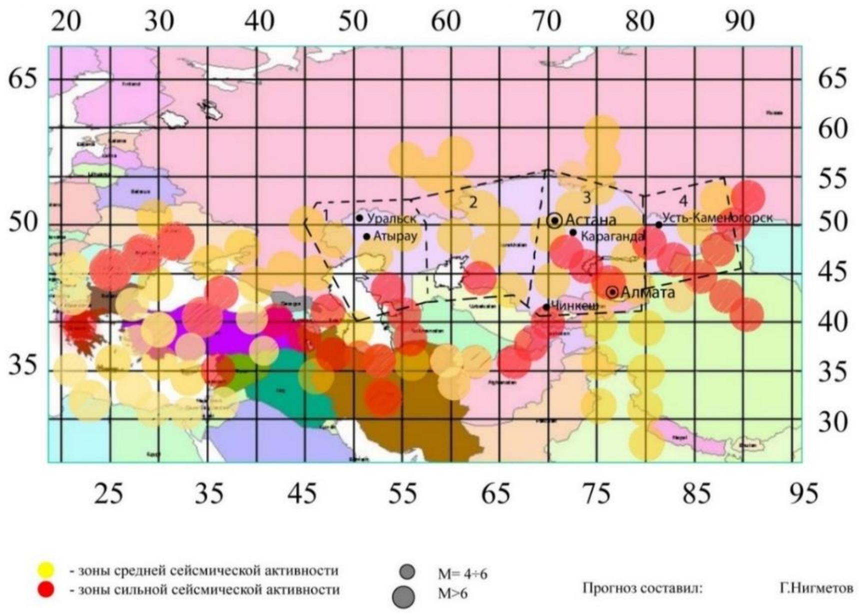

Figure 3: *PES map of the Almaty region, obtained in 2013-2018 as a result of the analysis of the manifestation of complex precursors.*

Let us consider one example of the application of a geographic information system for forecasting possible consequences of a possible earthquake with the parameters specified in Table 2. A PES map was obtained in the Almaty region.

To assess possible risks, the following parameters of the predicted earthquake hypocenter were used: coordinates 77 N, 42.85 E, M=7, depth 10 km (see Fig. 4 and 5), which coincided with the predicted zones. The risk forecast was completed in 2015 and reported at a conference in Almaty.

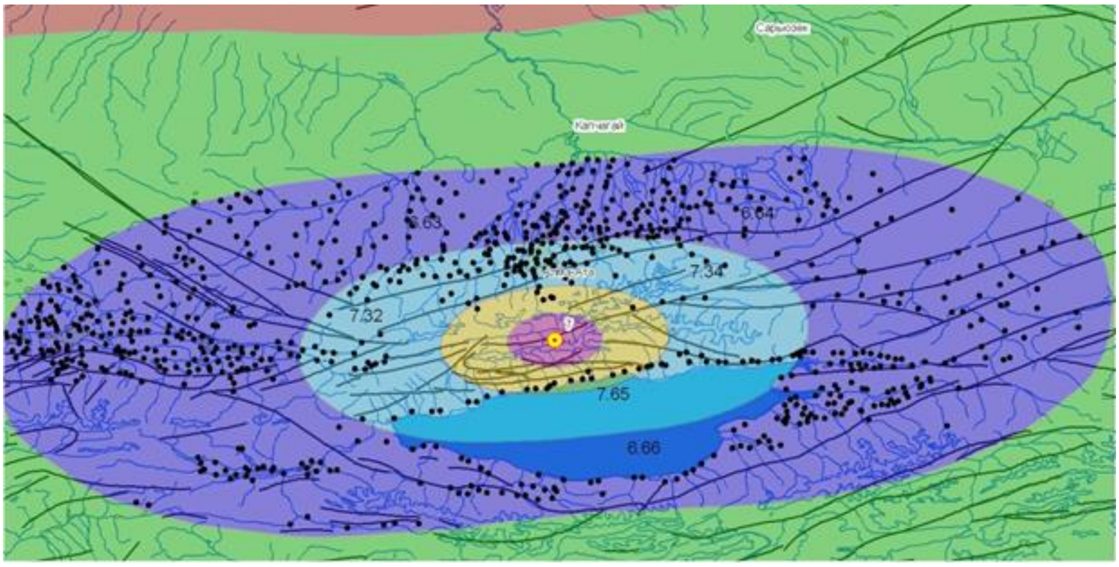

Figure 4: *Predicted field of vibration intensity for a possible earthquake 40 km south of Almaty.*

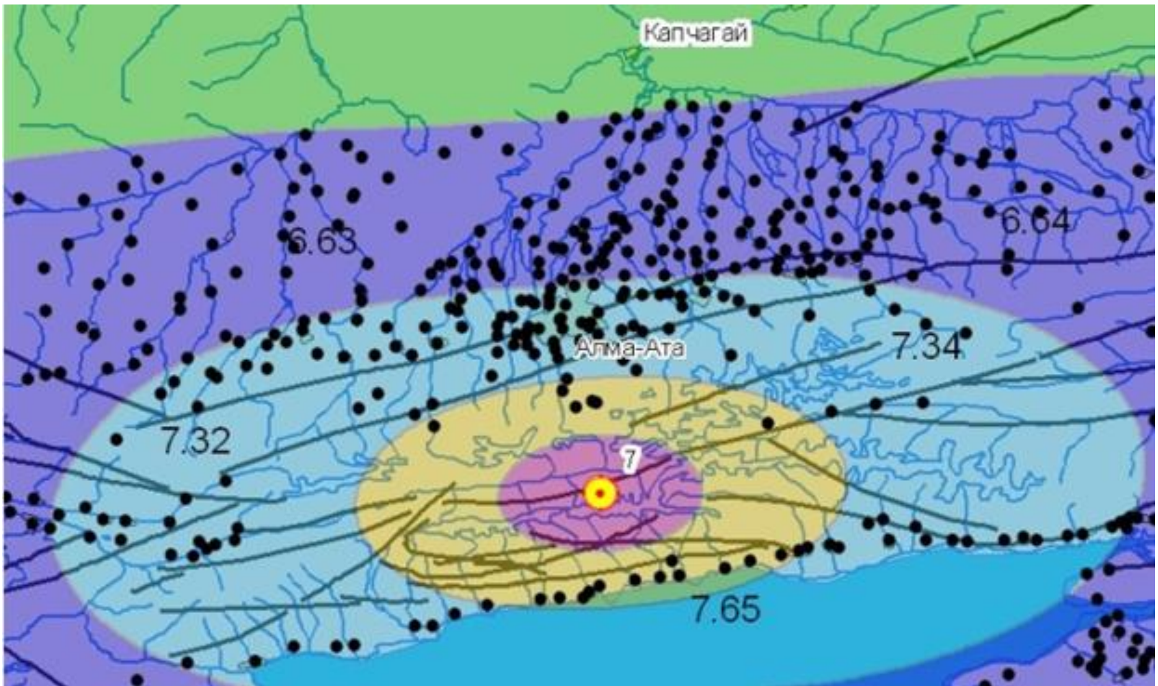

Figure 5: *Predicted field of oscillation intensity for a possible earthquake 40 km south of Almaty, with a close-up view of the oscillation intensity zones.*

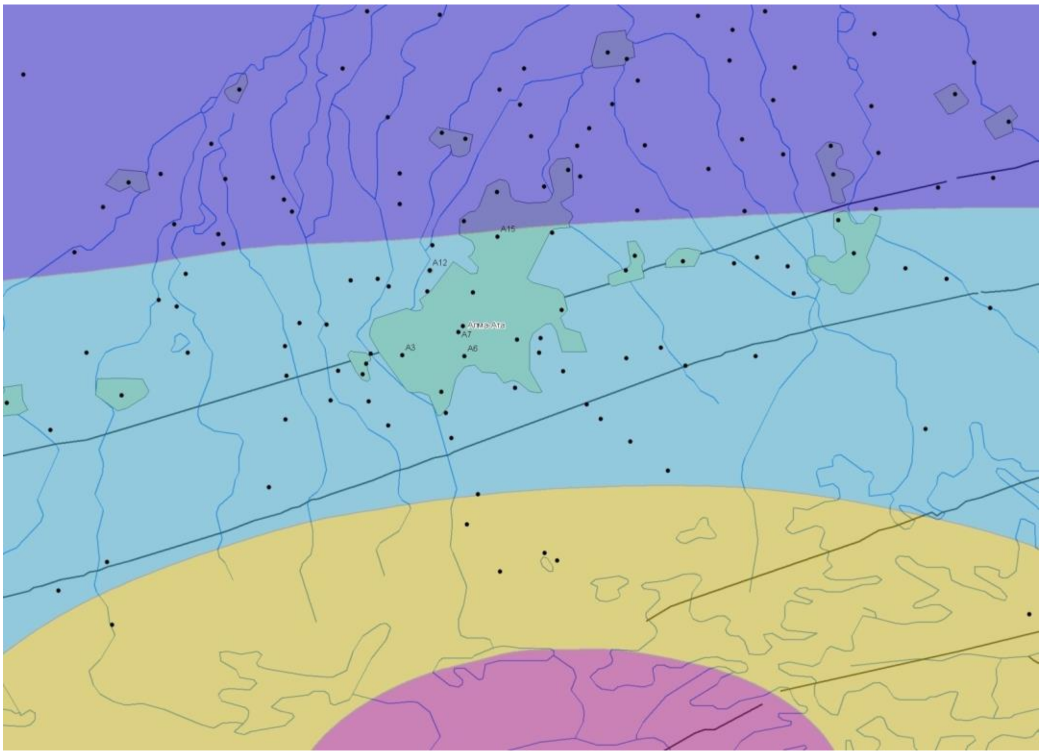

Figure 6: *Predicted field of oscillation intensity for a possible earthquake 40 km south of Almaty, with a close-up view of the oscillation intensity zones.*

Based on the results of the calculations performed for a possible earthquake source with the predicted parameters, the individual seismic risk will be:

$$Re_i = \frac{m}{T \times N} = \frac{300000}{10 \times 1500000}\left[\frac{1}{year}\right] = 2 \times 10^{-2}\left[\frac{1}{year}\right] \qquad (3)$$

where: m is the mathematical expectation of losses in the considered zone of a possible earthquake, people;

T – time during which a possible seismic event is predicted, (1-10 years) year.;

N is the number of people (1,500,000 people) located in the 6-point earthquake zone.

Thus, the risk under this scenario is 2000 times higher than the norm.

For a timely response to a possible seismic hazard in the Almaty region, it is necessary to create a system for monitoring and forecasting the territory in the areas predicted by the PES.

IV. Discussion

According to the medium-term forecast of seismic activity of the territory of Eurasia for the period from 2013 onwards, including 2026, developed by Nigmetov G.M. and presented at the Russian Expert Council on Forecasting Seismic Hazard and Risk (see 2.1 and 3.1). This forecast was first reported to the RES in 2008 as a forecast until 2009, then at regular meetings of the RES it was extended. The forecast came true for all destructive earthquakes: China (Sichuan), Kyrgyzstan, Kazakhstan, Chechnya, Tajikistan, Italy, Japan.

As can be seen from the forecast based on data from Nigmetov G.M., the most seismically active part of the territory of Kazakhstan is the southeastern part of the territory of the Republic of Kazakhstan.

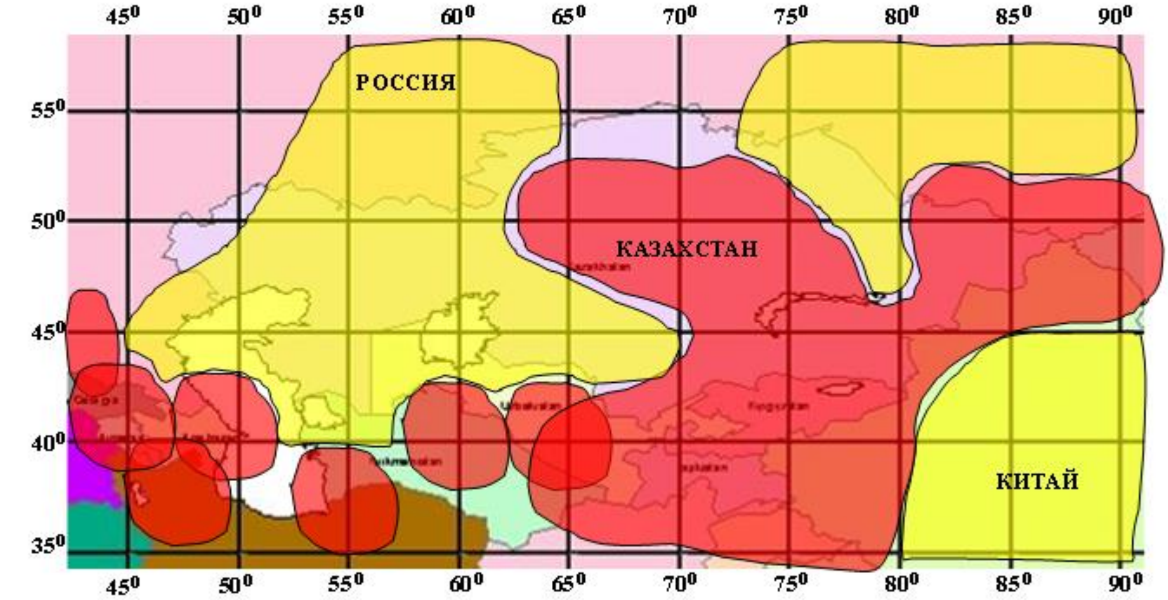

Figure 7: *Forecast of zones of increased seismic activity in the territory of the Republic of Kazakhstan and adjacent territories, which was presented by G.M. Nigmetov at a scientific and practical conference in 2009.*

Fig. 8-10 shows the manifestation of precursors before the earthquake of 04.03.24, which occurred on the border of Kazakhstan and Kyrgyzstan. As can be seen from the figures, the parameters of the precursors correspond to the criteria presented in Table № 2

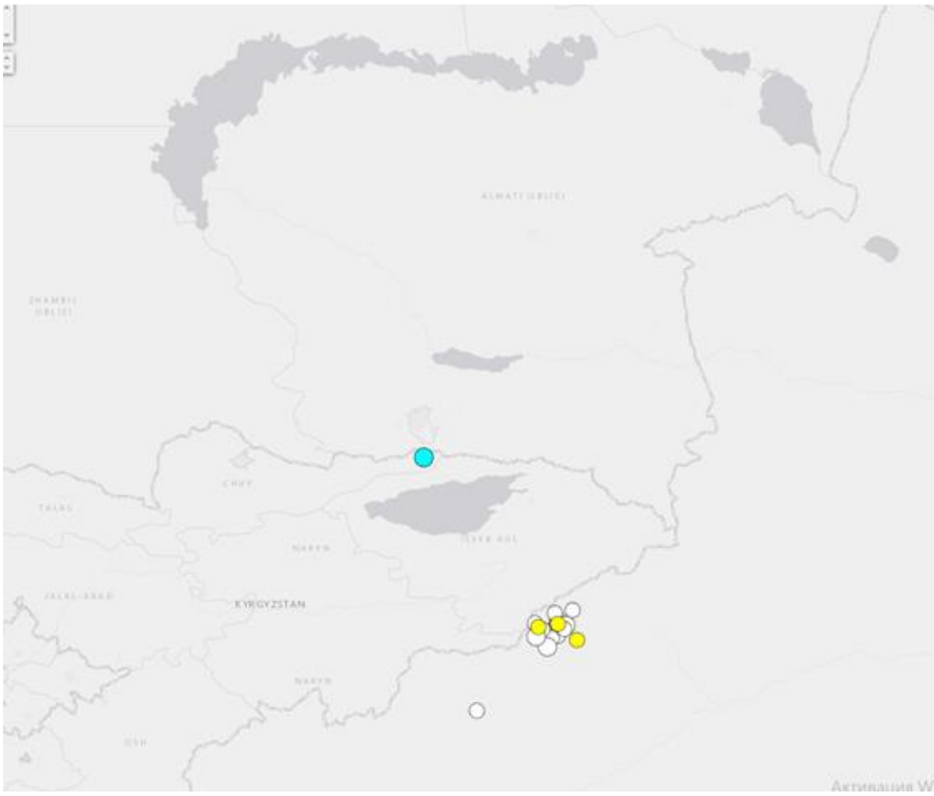

Figure 8: *Earthquake of magnitude 5.3 that occurred on 03/04/24 in the forecast zone on the border of Kazakhstan and Kyrgyzstan (according to the US Geological Survey).*

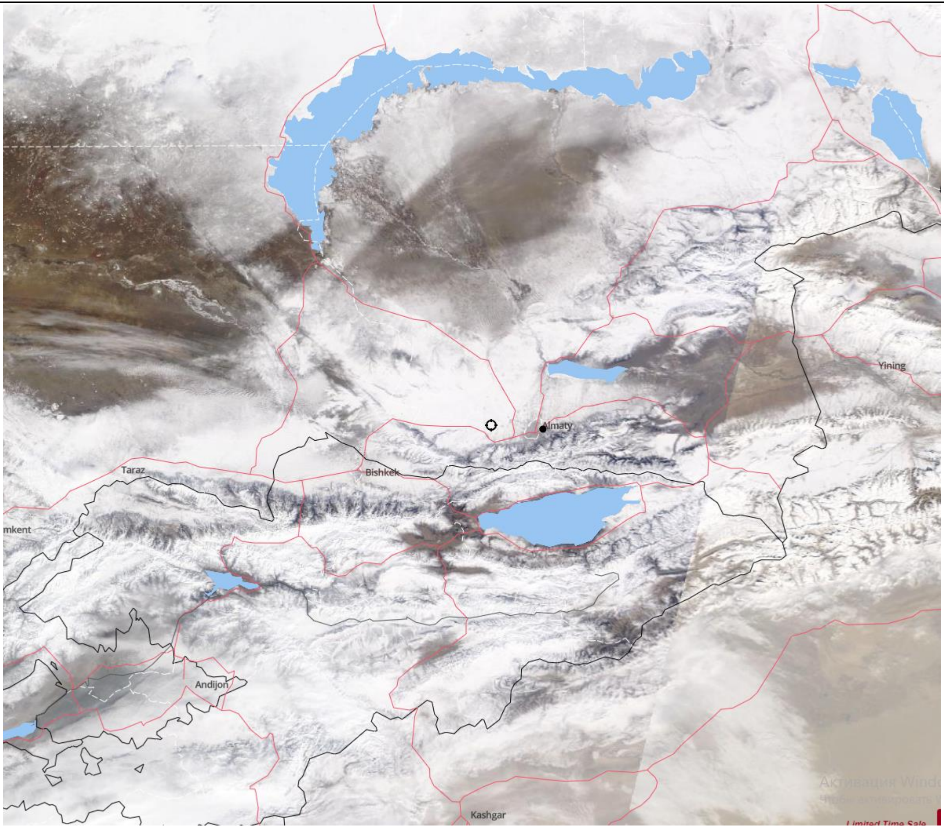

Figure 9: *Manifestation of a precursor in the cloudiness portrait before the earthquake that occurred on 04.03.24 on the border of Kazakhstan and Kyrgyzstan (according to the data of the image of 29.02.24 of the Terra satellite). A characteristic gap in the cloudiness in the area of the expected epicenter is visible.*

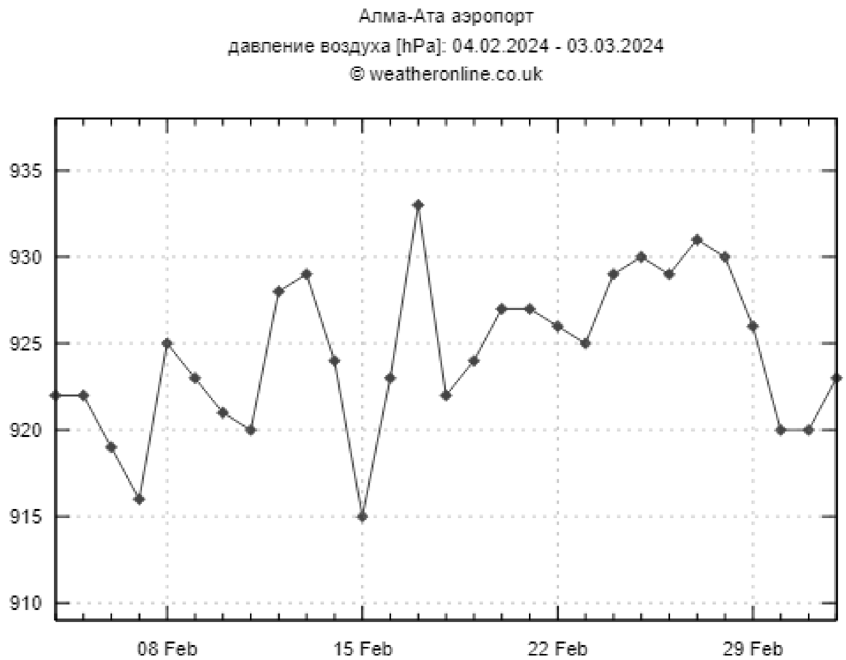

Figure 10: *Manifestation of a sharp drop in atmospheric pressure at the Almaty airport before the earthquake that occurred on 04.03.24 on the border of Kazakhstan and Kyrgyzstan (data obtained from Internet sources).*

To monitor seismic hazard and individual seismic risk for the population of the Almaty region, it is proposed to use the above-described end-to-end approach from PES forecasting, seismic resistance assessment to calculations of individual seismic risk using GIS.

At the first stage of the work, it is proposed:

1) to assess the seismic hazard of the territory in the vicinity of Almaty; for this, use the adapted models of Nigmetov G.M. and other authors for the analysis of geodynamic, seismic, geophysical, electromagnetic, meteorological, satellite data and determination of the coordinates of possible earthquake sources 2-7 days in advance with a magnitude of M less than 5 and M greater than 5; Determine possible earthquake sources;

2) perform work on the prompt assessment of seismic resistance of buildings and structures using the dynamic testing method, clarify the database on seismic resistance of buildings and objects in the territory of Eurasia;

3) adapt the model for assessing the consequences of strong earthquakes for the territory of Almaty and assessing individual seismic risk taking into account geological features and buildings;

4) develop a geoinformation system for the territory of Almaty and surrounding areas for predicting possible sources of strong earthquakes, predicting possible consequences of strong earthquakes, monitoring assessment of individual seismic risk and displaying monitoring information on seismic hazard and individual seismic risk taking into account individual blocks and buildings.

At the second stage of the work, it is proposed to modernize the technical and software equipment of the monitoring system. The modernization will be carried out based on the results of the trial operation of the system, clarification of the parameters of possible earthquake sources, a refined database of seismicity and seismic resistance, and refined criteria for assessing seismic hazard and risk for the region in question.

The results of the conducted research and the considered examples show that the accuracy of the results of forecasting the consequences of strong earthquakes depends on:

1) the accuracy of constructing the intensity field or macroseismic fields of earthquakes;

2) the degree of reliability of data on development and its seismic resistance;

3) the reliability of data on the population, tectonics and geology of the territories.

In the course of the conducted research and analysis, it was revealed that the terrain has a great influence on the intensity of the earthquake, as well as tectonic fault lines.

Long-term data calculated on GIS show that the geographic information system, with the help of which it is possible to construct and study in detail the macroseismic fields of earthquakes, constantly needs to update the data, in more expanded information about various territories of the world and its population, about their geological structure, as well as the latest data on tectonic faults, terrain and types of design solutions for development and its seismic resistance.

V. Conclusion

From higher research results it is clear that the individual risk for the population within 10 years. To introduce the Almaty norm in 2000, when urgent measures are required to reduce the risk, therefore it is necessary:

1) to specify the coordinates, depths and magnitudes of the earthquake zone at a distance of 100-200 km from the city boundaries;

2) to assess the seismic resistance of typical city buildings located in the i-th elements of the city districts and to update the database, presenting it in the form of the following table:

Table 3: *An example of the proposed form of a database on development for seismic resistance of buildings (for the updated GIS "Extremum" database).*

Name of the city district	1 element	2 element	3 element	i
X	7,2	6	7,1	
Y				

3) perform a risk assessment for i-th elements of city districts and identify elements with increased risk exceeding the risk standard by 2 or more times;

4) develop risk reduction measures (development of seismic hazard warning systems, increasing the seismic resistance of buildings, reducing seismicity at the base of buildings, demolishing emergency buildings and relocating the population to earthquake-resistant buildings)

5) after completing the measures, perform a re-assessment of the individual risk

6) if the individual risk is not exceeded in any of the i-th elements, the measures to prepare for a catastrophic earthquake are considered complete

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