RT&A, Special Issue No 5 (75)
Volume 18, November 2023

MONITORING OF INDIVIDUAL SEISMIC RISK AT ALL STAGES OF DEVELOPMENT OF A POSSIBLE EARTHQUAKE SOURCE

Gennady Nigmetov, Andrei Savinov, Temir Nigmetov

•

FGBU VNII GOCHS (FC), Russia
tagirmaks@mail.ru

Abstract

At the threat of a catastrophic earthquake, there is a need to ensure seismic safety of the population at all stages of seismic hazard development. First of all, it is important to determine the locations of possible earthquake sources and possible macroseismic fields created by them on the terrain. The effectiveness of measures on seismic safety of the population will depend on how correctly the possible earthquake source and seismic hazard zones, in which destructive seismic impact is expected, seismic resistance of buildings in these hazard zones, the number of population falling into the seismic zone, possible consequences have been determined. Knowing the possible consequences, it is easy to determine the necessary forces and means to prevent risks and rescue the population.

Keywords: seismic hazard, possible earthquake source, macroseismic field, dynamic-geophysical testing of buildings, building seismic resistance, individual seismic risk

I. Introduction

Seismic safety is a complex concept, and unlike seismic hazard and individual seismic risk, it cannot be unambiguously expressed by a single value. The main difference of seismic safety is its focus on prevention of possible risks, i.e. the goal of seismic safety is to ensure minimal damage and losses at all stages of development of a catastrophic earthquake. Three main stages of seismic event development can be distinguished:

Stage One - possible earthquake source is expected to be triggered;

Second stage - possible earthquake source triggering and possible threat of a second strong shock;

The third stage is the attenuation of the event:

For proper planning of measures to ensure seismic safety of population in the zone where destructive earthquake is expected with high probability, it is necessary to have monitoring information on possible earthquake sources, on time of each stage of earthquake, on zones of seismic loads in case of triggering of possible earthquake source, on seismic resistance of buildings, on possible destructions and losses, on required forces and resources.

In order to obtain real-time information on the above data, it is necessary to carry out monitoring observations, to have criteria to assess the degree of danger of seismic loads in case of possible earthquake source triggering, on the seismic resistance of buildings, on possible destruction and losses, on the necessary forces and resources**.**

At the first stage, when possible earthquake source triggering is expected, which may last for several years, it is necessary to determine as accurately as possible the coordinates, depth and power. For this purpose, historical data on earthquakes in the region and patterns of earthquake precursors, real monitoring data on seismic activity can be used.

In the second stage, which can last up to 2 months, it is important not only to organize rescue operations correctly and efficiently, but also to continue monitoring observations for timely assessment of the probability of a possible recurrence of a strong shock.

At the third stage - attenuation of the source zone, up to a year and more, when reconstruction works begin, it is also necessary to continue monitoring observations of seismic activity, seismic resistance of buildings and structures.

At all three stages of development and attenuation of seismic hazard and risk, it is required not to stop complex monitoring observations of seismic activity of the territory to ensure seismic safety of the population.

II. Methodology

The most dangerous and difficult to predict is the first stage of seismic event development. For proper planning of measures providing seismic safety of the population at the first stage it is necessary to determine as accurately as possible the coordinates of possible earthquake source, time and probability of its triggering, macroseismic field in case of possible earthquake source triggering taking into account tectonics, geology and relief of the territory, knowing the seismic resistance of buildings and structures to determine possible destruction, losses and risks.

The first stage of possible earthquake source preparation may last for years and may not always be realized by an earthquake, therefore at this stage it is important to have reliable predictive data or to have earthquake-proof buildings and structures. To determine the probability of possible earthquake source triggering by the manifestation of precursors it is proposed to apply expression (1), where the probability is defined as the difference of one minus the product of improbabilities of events by the manifestation of precursors according to the following dependence [7, 8].

$$P_z=1-\Pi_{i=1}^{i=n}(1-P_i) \quad (1)$$

Where,

P_z – triggering probability possible earthquake source

P_i – probability that at occurrence of the *i*-th precursor the triggering will take place possible earthquake source (Table 1).

If $P_z \geq 0.7$, it is assumed that the probability of triggering possible earthquake source is very high.

When the probability of possible earthquake source triggering is high (more than 0.7), knowing the possible earthquake source parameters (coordinates and power) and its triggering time, it is possible to calculate possible damage, losses and risks.

The mathematical expectation of losses is calculated using a geographic information system [9,10], which makes it possible to construct a macroseismic field taking into account the tectonics and geology of the area, to calculate possible damage and losses taking into account the proportion of buildings by type characterizing their seismic resistance and data on the population in settlements.

The individual risk of occupancy of people in damaged buildings in the considered seismically hazardous territory in the projected time interval, taking into account possible repeated seismic shocks, is proposed to be calculated according to the following formula:

$$Re_i(t)=P_z\times\Sigma_i^n m_i/(N_i\times T) \leq [Re_i] \quad (2)$$

Where,

P_z - probability of a main (repeated) strong seismic shock;

m_i – assumed losses of people in case of loss of bearing capacity of "ground-building" systems in the considered i-th element of the territory (building) after a repeated shock [4, 10, 11];

N_i – the number of people in the *i*-th element falling into the zone of dangerous seismic impact resulting in damage to buildings;

T – the period during which the main (repeated) seismic shock that causes damage to buildings will occur;

[Rei] - risk standard 10^{-5}[12]

Table 1: *Probability of triggering a possible earthquake source when a certain precursor manifests itself (data obtained from long-term observations) [5,6,7,8]).*

№	Type of precursor	Time of manifestation before the main shock	The regularity of the manifestation of the precursor	Main parameters of the precursor	Possible earthquake source parameters. Probability of triggering (Pi)
1	Geodynamic movements	1-7 days	regularly	Low-frequency rocking of the Earth's surface with the period up to 1.5 hours, amplitude up to 15 cm	0.8-0.95
2	Low-frequency noises	1-7 days	regularly	Low-frequency noise at 0.15 Hz and below	0.7-0.9
3	High-frequency noise	1-7 days	regularly	High-frequency noise with a frequency of more than 70 Hz	0.8-0.9
4	A sharp drop in atmospheric pressure (see example Fig. 3)	1-14 days Immediately before the earthquake (0.5 days) there is a quiescence	regularly	High-frequency noise with a frequency of more than 70 Hz	0.5-0.8
5	Lightning discharges and atmospheric manifestations	1-4 days There's a lull before the earthquake	Lightning discharges regularly	They are sampled along (parallel to) tectonic faults (see Figures 2,6,8)	0.5-0.7
6	Atmospheric luminescence	0,5-1 days	Not regularly	A certain area stands out brightly	0.7
7	A portrait of cloudiness	4 days		They are beaten off in the area of tectonic faults, have a special linear, striated character (see Fig.7)	0.5-0.7
8	Forshock activity	Observed	Not regularly	They are hammered in a specific zone or along tectonic faults (see Fig. 10).	More than 0.6

The mathematical expectation of population losses is calculated using the Extremum geographic information system (GIS).

Calculation of possible consequences from repeated strong shocks should be performed taking into account possible reduction of seismic resistance of buildings. At present, such procedure is not provided in GIS "Extremum". The method of dynamic tests [11, 13] is proposed to be used for operational assessment of the seismic resistance of buildings that have fallen into the zone of seismic impact of more than 6 points. Based on the results of dynamic tests, the database in GIS "Extremum" should be adjusted.

In GIS "Extremum", classification by seismic scales of ISC-64 is currently used to form a database on buildings, and type A (local materials), type B (masonry and block), type C (earthquake-resistant C7, C8 and C9) are distinguished. In the database on buildings, included in the geoinformation system for assessing the consequences of strong earthquakes in the territories, the share of buildings by types is presented in percent (see Table 2).

Fig. 1: *An example of a mixed, dense development in Istanbul on hilly terrain.*

Table 2: *Example of filling in the database on development by type of buildings (based on data from 1999-2000, from the GIS "Extremum" database).*

City name	A/ height, m	B/ height, m	C6/ height, m	C7/ height, m	C8/ height, m	C9/ height, m
Nalchik	0.2/3	0.21/6	0.2/15	0.39/3	0	0

As it can be seen from the example (see Table 2), in the considered city according to the data of 1999-2000 there is no building with seismic resistance C8 and C9, it is clear from the example that the database on seismic resistance requires its constant updating. The data on seismic resistance are linked to the seismic scale and give only discrete values of seismic resistance without taking into account operational wear, i.e. they do not reflect real data on seismic resistance of buildings. The Extremum GIS database needs to be corrected and can be considered for evaluation analysis. Adjustment of the database can be made either by decreasing or increasing the share of buildings by classes A, B, C6, C7, C8, C9. Or it is proposed to divide the city territory into separate area elements with prevailing seismic resistance (see Table 4).

To assess the technical condition, stiffness and earthquake resistance of buildings and structures, it is proposed to apply the "STRUNA" technology [11]

The essence of the method is based on the fact that through vibrations it is possible to assess the stiffness of the structure, and through stiffness it is possible to assess the technical condition and earthquake resistance of structures.

To evaluate the possible resonance between the ground and the structure, sensors are installed on the ground and the structure.

The stiffness deficit is estimated using the following relationships [4-8]:

$$\Delta_x = ([f_x]^2 - f_x^2)\times100/ [f_x]^2, \quad (1)$$
$$\Delta_y = ([f_y]^2 - f_y^2)\times100/ [f_y]^2, \quad (2)$$
$$\Delta_z = ([f_z]^2 - f_z^2)\times100/ [f_z]^2, \quad (3)$$

where f_x, f_y, f_z — values of natural vibration frequencies of the structure;
$[f_x]$, $[f_y]$, $[f_z]$ — normative values of natural vibration frequencies of the structure, derived from the project or by calculation;
Δ_x, Δ_y, Δ_z — stiffness deficit in % in axes X, Y, Z (see Table 3).
Based on the obtained data on the stiffness deficit, the technical condition of the structures and their seismic resistance are determined.

Table 3: *Percentage of stiffness reduction (square of frequency of natural vibrations of the structure), depending on the category of technical condition*

Type of construction	Percentage of relative reduction in stiffness of the structure under different conditions				
	Very Good	Good	Fair	Poor	Very Poor
With reinforced concrete frame	0–25	25–43	43–57	57–71,4	71,4–100
With metal frame	0–16.7	16.7–33	33–50	50–67	67–100
Brick	0–16.7	16.7–33	33–50	50–75	75–100
Wooden	0–20	20–27	27–40	40–67	67–100

Dynamic tests are proposed to be performed on typical elements of settlements with the same type of buildings. The GIS database should contain data on earthquake resistance (see Table 4) for each element of the structure.
Then the database in GIS "Extremum" is proposed in the following form (see Table 4)

Table 4: *Example of the proposed form of the database on construction by types of buildings (based on 1999-2000 data from the GIS "Extremum" database).*

City name	1-th element	2-th element	**3**-th element	4-th element	5-th element	6-th element	…	….	n
X	7.2	6	7,1	9	0	0			
Y									

The data in Table 4 will allow to lay down the real seismic resistance of building elements, obtained from the data of dynamic tests in points or accelerations.

III. Example of individual seismic risk assessment for the territory of Turkey

For estimation of probability of possible earthquake source triggering, let's consider an example of manifestation of precursors before strong earthquake in Turkey 06.02.23. Results of estimation of precursor activity are presented in Table 5.

Fig. 2: *Glow before the earthquake in Turkey 06.02.23 (taken from Internet sources)*

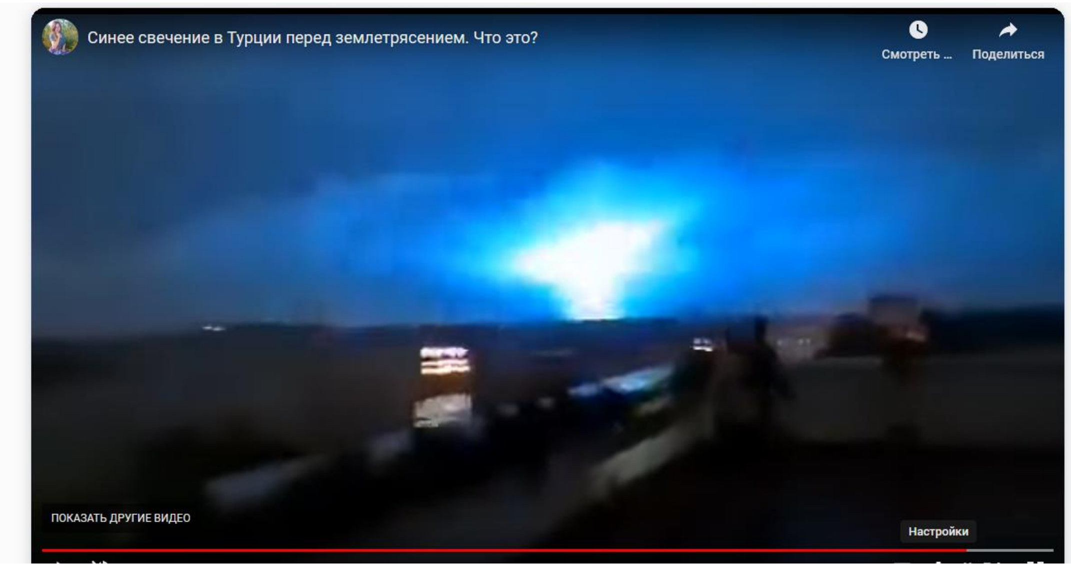

Fig. 3: *Glow before the earthquake in Turkey 20.02.23 (taken from Internet sources)*

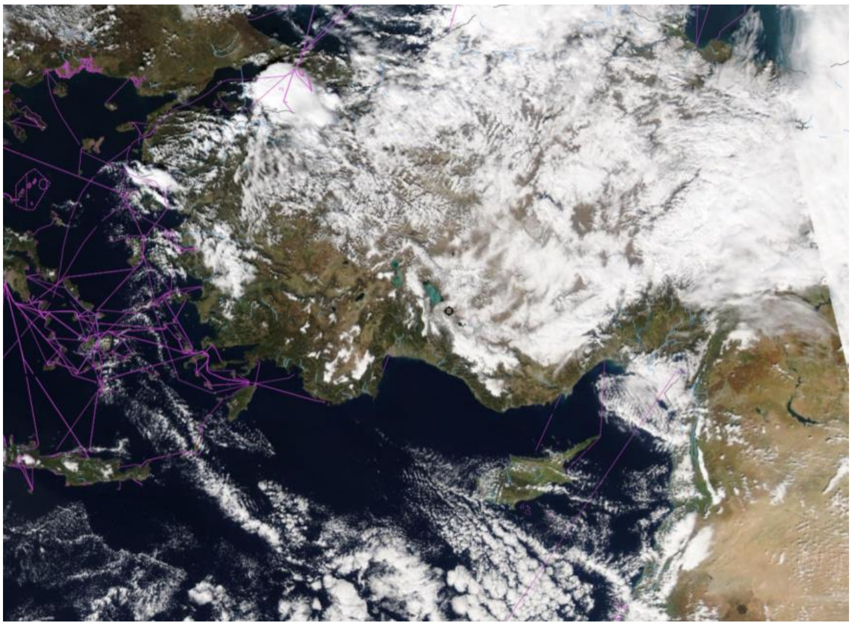

Fig. 4: *Portrait of cloudiness 02.02.23 Suomi satellite, the cloudiness repels tectonic faults on the border of Syria and Turkey and from the island of Cyprus to Greece (according to Multimaps, taken from Internet sources). Cyprus to Greece (according to Multimaps, taken from internet sources).*

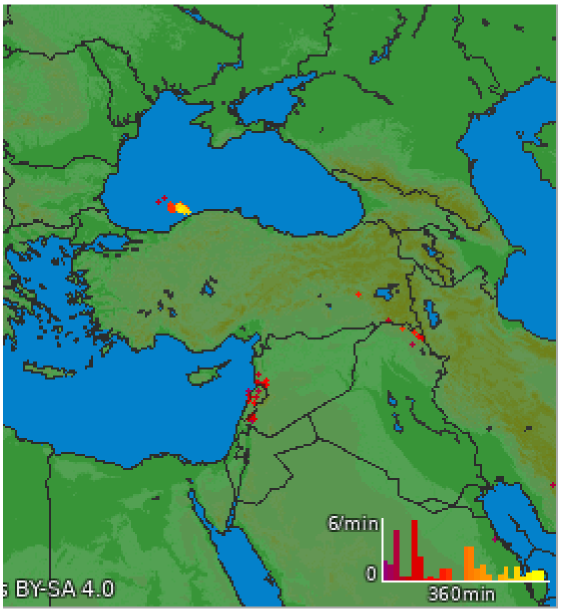

Fig. 5: *Thunderstorm activity along the right tectonic fault 02.02.23 at the border of Turkey and Syria (taken from Internet sources)*

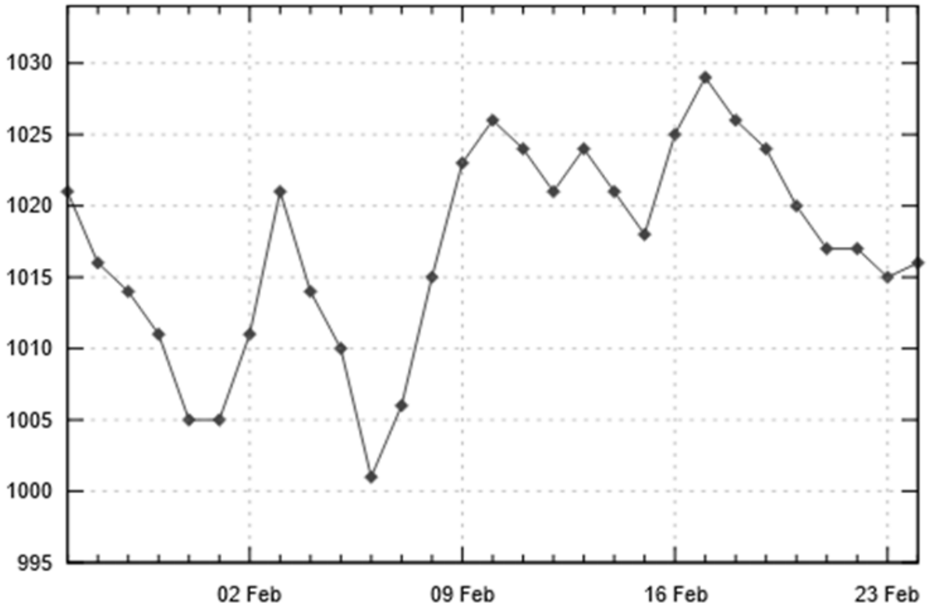

Fig. 6: *Sharp drop of atmospheric pressure before the strong earthquake in Turkey on 06.02.23.*

Fig. 7: *Forshock activity in the period from 24.01.23 00:00 to 05.02.23 23:59 before the strong earthquake on 06.02.23 (from data of the US Geological Service).*

At that time, the probability of triggering the main shock of the earthquake in Turkey could have been

$$P_z=1-\prod_{i=1}^{i=n}(\mathbf{1}-\boldsymbol{P_i})=1-(1-0,7)\ (1-0,7)(1-0,7)(1-0,5)=0,9865$$

The probability of triggering an aftershock of the Turkish earthquake could have been

$$P_z=1-\prod_{i=1}^{i=n}(\mathbf{1}-\boldsymbol{P_i})=1-(1-0,7)(1-0,7)(1-0,7)(1-0,7)=0,9919$$

Using data on tectonics, geology, coordinates and earthquake magnitude, data on earthquake resistance of the building with application of geoinformation model we will perform calculations on estimation of possible damages and mathematical expectation of losses. The results of calculations are presented in Fig. 8.

Table 5: *Time manifestation and parameters of precursors before earthquakes in Turkey 06.02.2023.*

№	Type of precursor	Time of manifestation before the main shock	Main parameters of the precursor	Possible earthquake source parameters. Probability of triggering
1	A sharp drop in atmospheric pressure	One to six days before an earthquake, there's a lull	Abrupt 72-hour drop and rise of atmospheric pressure 25-26 hPa (see Fig. 6)	0,7-0,5
2	Lightning discharges and atmospheric manifestations	In four days. There's a lull before an earthquake	Tectonic faults were repelled (see Figures 2,3,5)	0,7
4	A portrait of cloudiness	In four days.	Tectonic faults were repelled (see Fig. 4)	0,7
5	Forshock activity	Observed	Tectonic faults were repelled (see Fig. 7)	More than 0.7

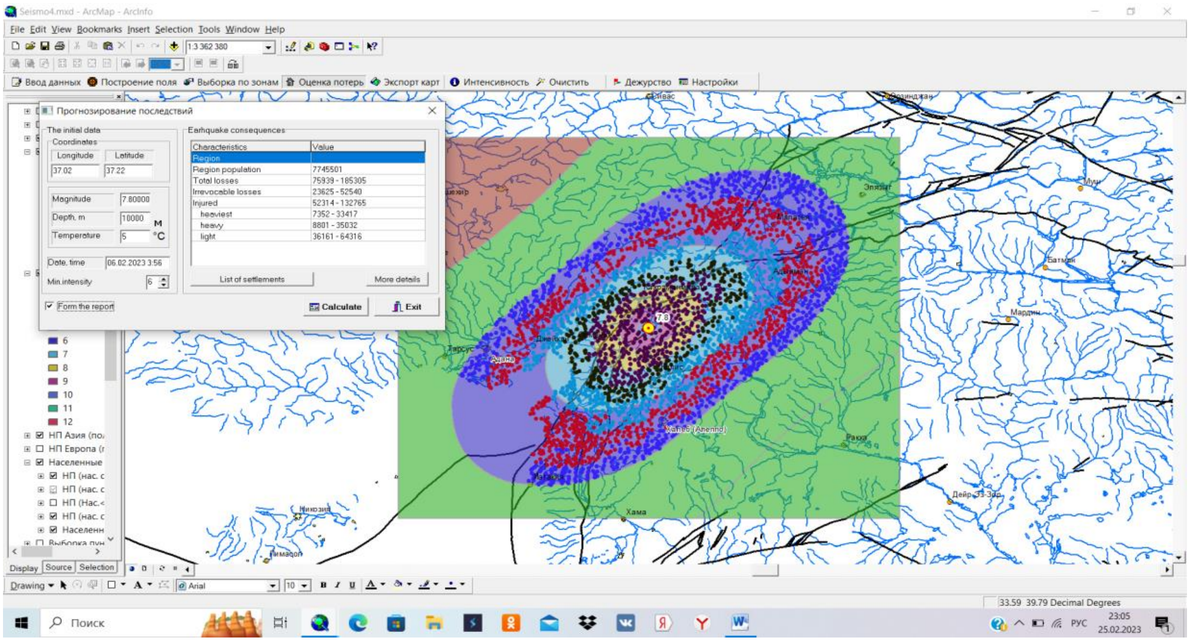

Fig. 8: *Forecast of possible consequences from the strong aftershock in the Republic of Turkey, which occurred on 06.02.23.*

Then, applying the formula (1) and (2) and the results of calculations on the model we estimate the risk for the population taking into account a possible strong aftershock, the risk for the population in the epicentral zone amounted to

$R_{ei}(t) = 0,9919 \times \frac{52540}{7745501 \times 1} = 0,006728 = 6,728 \times 10^{-3}$, risk is significantly (almost 1000 times) higher than the norm 10^{-5}-10^{-6} [13].

IV. Conclusions and recommendations

Application of the proposed technology for monitoring seismic hazard and individual seismic risk will make it possible to make timely decisions to ensure seismic safety of the population.

The basis for decision making should be:

Monitoring of seismic activity of the area to determine possible earthquake source and the probability of triggering;

Assessment of the earthquake resistance of buildings and updating of the building database;

Assessment of possible consequences if possible earthquake source is likely to be triggered; Identification of areas with increased (more than 10^{-5} 1/year) individual risk to the population;

Timely planning of measures to reduce individual seismic risk for the population located in high-risk areas.

References

[1] Ismail Ibrahim, K.M.H., Ibrahim, T.E. Effect of historical earthquakes on pre-stressed anchor tie back diaphragm wall and on near-by building. HBRC Journal. 2013. 9(1). Pp. 60–67. DOI:10.1016/j.hbrcj.2013.02.008.

[2] Hoveidae, N., Fathi, A., Karimzadeh, S. Seismic damage assessment of a historic masonry building under simulated scenario earthquakes: A case study for Arge-Tabriz. Soil Dynamics and Earthquake Engineering. 2021. 147. Pp. 106732. DOI:10.1016/j.soildyn.2021.106732.

[3] Saretta, Y., Sbrogiò, L., Valluzzi, M.R. Seismic response of masonry buildings in historical centres struck by the 2016 Central Italy earthquake. Calibration of a vulnerability model for strengthened conditions. Construction and Building Materials. 2021. 299. Pp. 123911. DOI:10.1016/j.conbuildmat.2021.123911.

[4] Stepinac, M., Lourenço, P.B., Atalić, J., Kišiček, T., Uroš, M., Baniček, M., Šavor Novak, M. Damage classification of residential buildings in historical downtown after the ML5.5 earthquake in Zagreb, Croatia in 2020. International Journal of Disaster Risk Reduction. 2021. 56. Pp. 102140. DOI:10.1016/j.ijdrr.2021.102140.

[5] Verdum, G., Bersch, J.D., Guerra, F.L., Socoloski, R.F., Giordani, C., Zucchetti, L., Masuero, A.B. Mortar coating degradation in historical buildings facades from Rio Grande do Sul – Brazil. Construction and Building Materials. 2021. 310. Pp. 125221. DOI:10.1016/j.conbuildmat.2021.125221.

[6] Yasser, E.M., Rakha, T. A scoping review of non-destructive testing (NDT) techniques in building performance diagnostic inspections. Construction and Building Materials. 2020. 265. DOI:10.1016/j.conbuildmat.2020.120542.

[7] Jiménez, B., Saloustros, S., Pelà, L. Seismic vulnerability index method for hybrid timber–masonry structures. Numerical calibration and application to the city of Valparaíso, Chile. Journal of Building Engineering. 2021. 44. Pp. 103185. DOI:10.1016/J.JOBE.2021.103185.

[8] The Possibility of Vibrodynamic Data from Phone Accelerometers for the Rapid Assessment of the Technical Condition of Buildings and Structures Use / A. Savinov, G. Nigmetov, T. Nigmetov, R. Galliulun // Proceedings of STCCE : International Scientific Conference on Socio-Technical Construction and Civil Engineering 2022: Lecture Notes in Civil Engineering, Kazan, April 21–29, 2022. Vol. 291. - Switzerland: Springer Nature, 2022. - P. 371-379. – DOI 10.1007/978-3-031-14623-7_33. – EDN HJSTRH.

[9] Nigmetov G.M., Larionov V.I., Frolova N.I., Suchshev S.P. Complex Assessment of Seismic Hazard and Seismic Risk of Territories // *Proc. of the Eight Internat. Conf. on Soil Dynamics and Earthquake Eng.* Istanbul, Turkey, 1997 (a).

[10] Nigmetov G.M., Larionov V.I., Frolova N.I., Suchshev S.P., Ugarov A.N. GIS Application for Seismic Hazard and Risk Assessment of Urban Areas // *Proc. of the IASPEI Assembly.* Thessaloniki, Greece, 1997 (b).

[11] Savinov, A., Nigmetov, G., Nigmetov, T., Galliulun, R. The Possibility of Vibrodynamic Data from Phone Accelerometers for the Rapid Assessment of the Technical Condition of Buildings and Structures Use 2023. Pp. 371–379.

[12] Nigmetov, G., Akatev, V., Savinov, A., Nigmetov, T. Estimation of seismic resistance of buildings by the dynamic-geophysical method, taking into account the peculiarity of the interaction of the seismic wave with the "soil-construction" system. Structural Mechanics and Analysis of Constructions. 2018. 1. Pp. 24–30.

[13] The use of elastic oscillations of different wavelengths to evaluate the dynamic parameters of buildings and structures and assess the strength of materials of the building construction Savin S., Tsakalidis V. COMPDYN 2015 - 5th ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering. 5. 2015. C. 706-720.