ASSESSMENT OF INDIVIDUAL SEISMIC RISK FOR THE POPULATION, TAKING INTO ACCOUNT THE ACTUAL SEISMIC RESISTANCE OF BUILDINGS AND THE SEISMICITY OF SOILS

Gennadiy Nigmetov, Andrey Savinov, Temir Nigmetov

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FGBU VNII GOCHS, Russia

tagirmaks@mail.ru savandr198@mail.ru t.nigmetov@yandex.ru

Abstract

In preparation for a catastrophic earthquake, it is important to plan and implement timely organizational and technical measures to protect the population in the zone of possible destructive seismic impact. In order to quantitatively assess the level of earthquake hazard, the vulnerability of buildings and possible losses among the population, the integral value of individual seismic risk is proposed. For a reliable assessment of individual seismic risk, it is necessary to know the parameters of the possible earthquake source, the macroseismic field, the seismic resistance of buildings caught in the 6-point zone of seismic impact, the seismicity of soils at the base of buildings and possible human losses. The methods currently used to assess individual seismic risk are based on many years of statistical data. We propose an end-to-end calculation-experimental approach to estimate possible losses and individual risk based on actual data on hazard, seismicity and earthquake resistance.

Keywords: earthquake, buildings, possible earthquake source

I. Introduction

The consequences of catastrophic earthquakes and individual seismic risk depend on many factors. But the most important factors on which individual seismic risk depends are seismic hazard, seismic vulnerability, or the earthquake resistance of buildings and the seismicity of soils. With timely and reliable short-term earthquake forecasting and notification of the population, up to 100% of the population can be protected, but at present there are no reliable methods for short-term earthquake forecasting. It is possible to protect the population by placing them in earthquake resistant buildings that have been properly designed with consideration of the seismicity of the soils at their base. The projected earthquake resistance of buildings is calculated according to the seismicity of the grounds at the base of the buildings. Since earthquake-resistant construction requires increased funding, it is important that the seismicity of the construction site, obtained in the surveys, corresponds to the actual data.[1] For existing buildings that have already been constructed, including those built using previously adopted norms, periodic verification of the earthquake resistance and seismicity of the sites is required. [2] An integral criterion of individual seismic risk is proposed for a comprehensive assessment of public safety, taking into account the earthquake resistance of buildings and seismicity of the site. When an earthquake threatens or after an earthquake, a mass rapid assessment of the earthquake resistance of buildings is required [3]. Existing rapid seismic testing methods are based on visual inspections that focus on the technical condition of the building and therefore provide an approximate rough estimate of earthquake resistance. Visual inspection, even with the use of traditional methods of instrumental control, fails to reveal hidden defects and take into account their impact on the integral stiffness of the building, which ensures the seismodynamic impact perception. The problem is that traditional methods of instrumental control, by means of which the pointwise examination of strength, reinforcement and structural cross-section do not allow to estimate the stiffness of each separate structure and the integral stiffness of the whole structural system.[4]

Thus, to assess individual seismic risk at different stages of seismic hazard development, taking into account the actual data on the seismicity of soils and the earthquake resistance of buildings, instrumental methods are required to determine the integral stiffness of the building, on the basis of which the actual seismicity of soils in the building base and its earthquake resistance can be estimated.

II. A method for calculating individual seismic risk using real data on seismic hazard, earthquake resistance and seismicity of soils.

Usually, a possible earthquake source (PES) in an earthquake zone forms over several years or decades, then triggers or discharges in the form of one or more strikes within a year, then fades out and a new PES occurs in a new location. [5]

Calculation of individual seismic risk must be performed at different, time-distributed stages of the PES:

1)at the PES threat stage, its projected parameters are determined: coordinates, depth and magnitude, time of possible triggering, then using a geographic information system (GIS) it is proposed to estimate consequences and individual risk for populations falling into the projected 6-point zone of seismic impact;

2) when the PES is triggered (the stage of the main strike) on the basis of real data of the earthquake origin obtained from geological services, an operative assessment of consequences and risks is made; the data obtained helps to promptly make decisions on organization of rescue works, verification of earthquake resistance of damaged buildings, population evacuation, and prevention of effects from secondary hazards;

3) assessment of possible risks from possible strong aftershocks is carried out by forecasted parameters of aftershocks, time of their possible triggering

4) after the main shock and aftershocks, data on the decay time of the epicentral zone and the time and parameters of the emerging PES are predicted for which the risks are calculated.

For short-term PES triggering locations estimation we suggest to use a complex approach based on the analysis of cloud cover data using satellite images, wind gust and thunderstorm activity maps, spectral analysis data of dynamic-geophysical observations.[6] Fig.1 shows an example of medium-term seismic activity forecast for the Black Sea-Caspian Sea region based on the complex method of seismic activity assessment. Regularities of the sequence of earthquake precursors manifestation, used in the complex approach, are given in Fig. 2 and 3. On the figures the entrance times of the earthquake precursors of the main strike and the strong aftershock are clearly seen by the example of the Nepal earthquake of 25.04.15.

Fig.3 shows how the cloud portrait shows characteristic " striped" anomalies, showing the possible location of PES triggering.

To calculate the macroseismic field from PES and to determine the boundaries of the 6-point zone, GIS uses data on tectonics, geology and terrain in the area of PES. In addition to data on seismic parameters in the form of a macroseismic field, real data on earthquake resistance are needed to assess possible consequences and risks. [7]

Real data on the seismic resistance of buildings and structures in the examined 6-point zone are proposed to be obtained by dynamic testing. With the help of dynamic tests we obtain the integral stiffness of buildings, which is directly proportional to the square of the frequency of natural

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vibrations of the building, the stiffness of the soil mass is also directly proportional to the square of the frequency of soil vibrations.

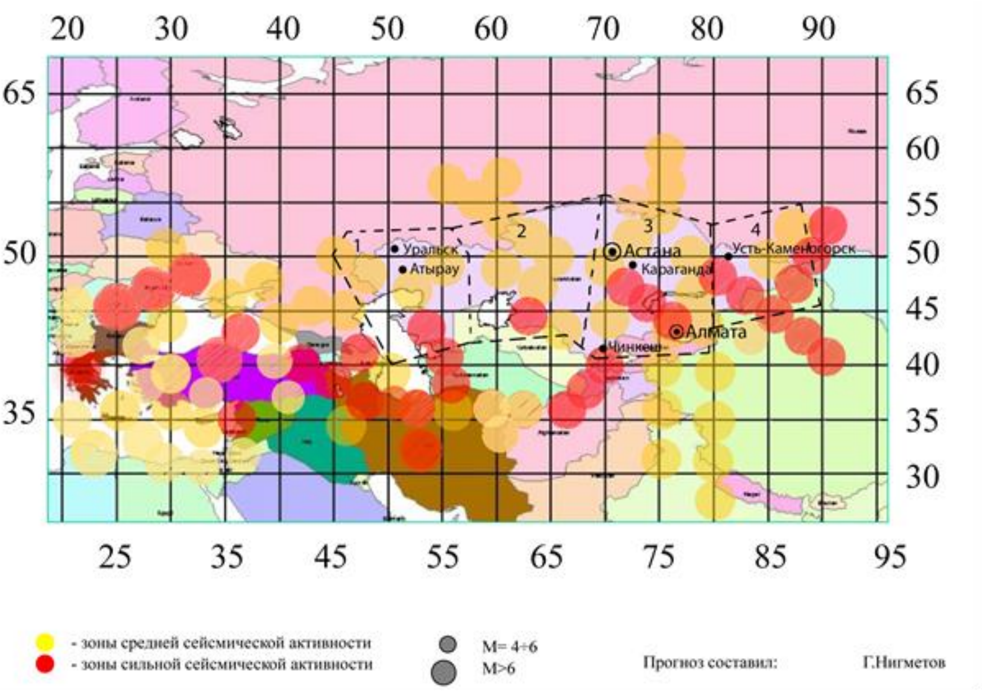

Figure 1: *Forecast of zones of increased seismic activity of the Black Sea-Caspian Sea region according to comprehensive analysis of precursors.*

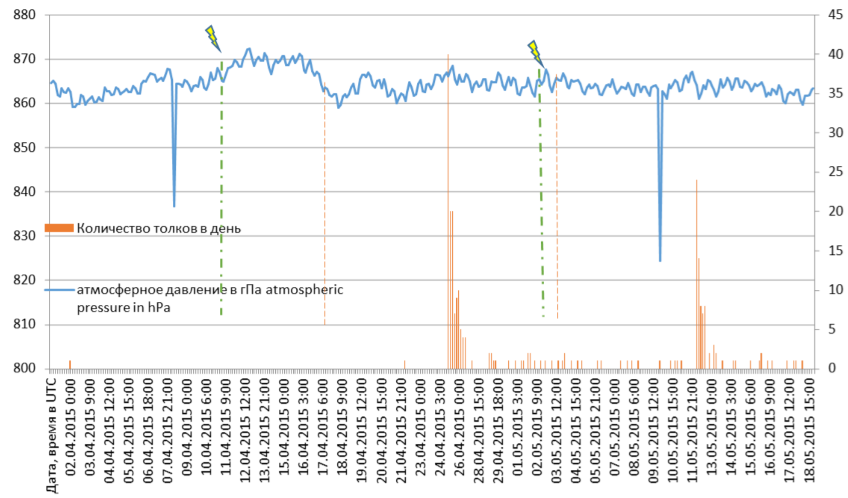

Figure 2: *Sequence of precursors of atmospheric pressure drop and lightning discharges on the example of the Nepal earthquake on 25.04.15.*

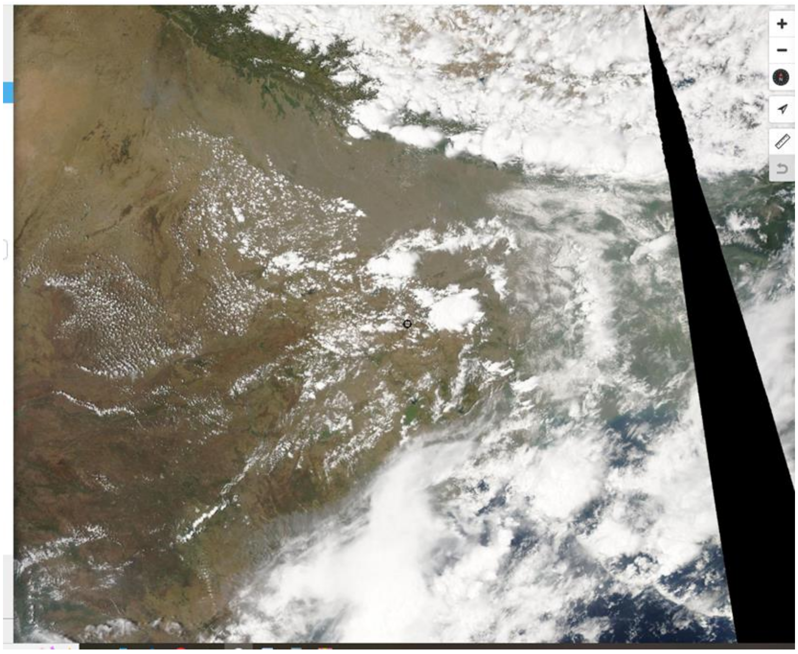

Figure 3: *The cloud cover before the strong earthquake in Nepal on 25.04.15.*

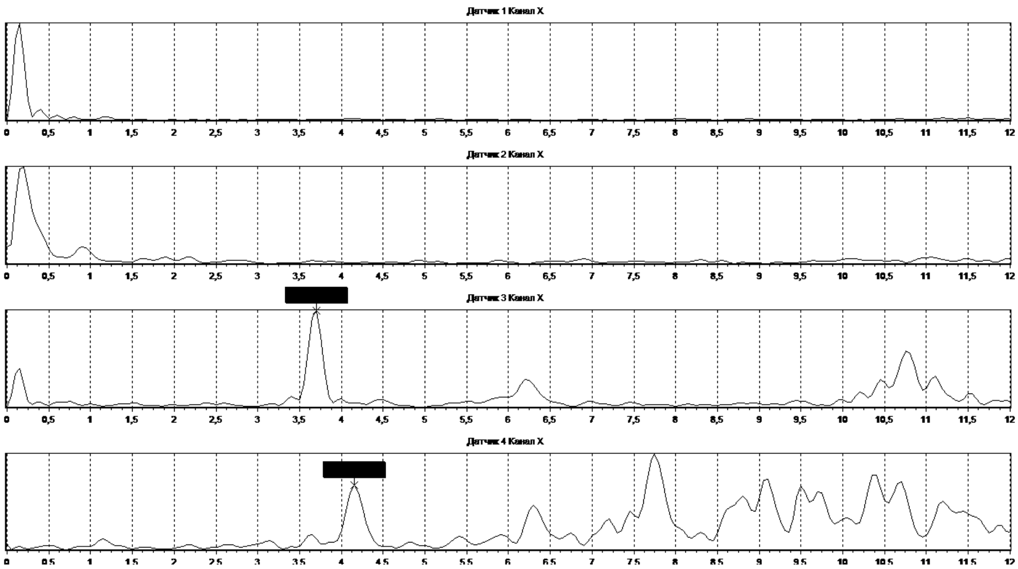

Figure 4: *Example of natural frequencies along the X-axis obtained in the dynamic tests of the historic building.*

To calculate the value of acceleration of earthquake resistance in dynamic tests through the square of the frequency, the following relation is proposed:

$$\boldsymbol{A} = \frac{4*\pi^2*\Delta d*f^2}{k_0*k_1*k_\varphi*\beta(T)} \quad ,$$

where

Δd – the maximum allowable displacement of the building;

k_0 – coefficient, taking into account the peculiarity of the structural solution and the degree of its importance K_0 [7];

$\boldsymbol{k_1}$– a coefficient taking into account acceptable damage k_1;
$\boldsymbol{k_\varphi}$ – coefficient, taking into account the dissipative properties of the structure, $\boldsymbol{k_\varphi}$;
$\boldsymbol{\beta(T)}$ – dynamism factor of a structure ;
$\boldsymbol{f}$ – natural frequency of the building.[8]

Thus, to calculate the value of individual risk, we can get real data on the possible seismic hazard, the earthquake resistance of buildings, and data on the possible number of people falling into the 6-point zone of seismic hazard.

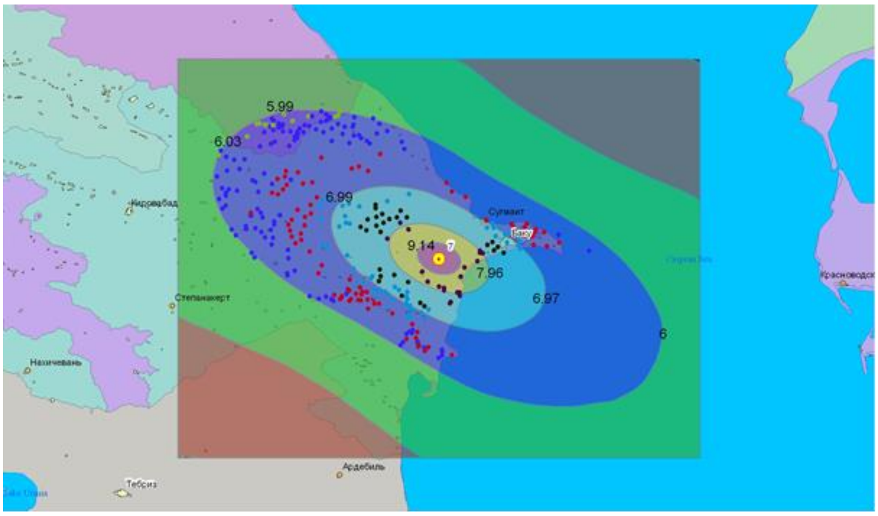

Figure 5: *Estimation of possible impacts for the predicted possible earthquake source.*

Based on real data on earthquake consequences the individual seismic risk is determined as quotient of mathematical expectation of losses in the considered 6 point zone of possible seismic event divided by time when earthquake is expected and by number of people in the considered 6 point zone.

$$Re_i = \frac{m_6}{T \times N_6} \leq [\, Re_i],$$

where:
Re_i – individual seismic risk, $\frac{1}{year}$;
[Re_i]- individual seismic risk norm;
m_6 – mathematical expectation of losses in the considered 6-point zone of possible earthquake, pers.;
T – time during which a possible seismic event is predicted, year
$\boldsymbol{N_6}$ – number of people in the considered 6-point zone of possible earthquake.

III. Results of calculation of individual seismic risk for the population of the Black Sea-Caspian Sea region.

Table 1 shows examples of calculations of individual seismic risks performed using the geoinformation system "Extremum". Calculations on the projected PES were performed for the Black Sea-Caspian Sea region. The GIS database on seismic resistance of buildings and seismicity of sites was specified for Krasnodar and Stavropol regions by the method of dynamic tests.

Table 1: *Assessment of possible individual seismic risk of territories for the population in the area of the Black Sea-Caspian Sea region.*

№	Location of possible earthquake origin (Country, nearest settlement, coordinates)	Predicted power of earthquake source M, depth of source H.	Time interval of possible triggering, year.	Possible projected individual risks, 1/year.	Excess of the projected risk over the risk rate equal to 10^{-5}1/year.
1.	Ukraine, 47 N Latitude, 32 E Longitude.	M=6, H=15 km	≥10	3×10^{-4} 1/year.	30 times.
2.	Ukraine, Romania, 47 N Latitude, 30 E Longitude.	M=6, H=15 km	≥10	$1{,}8\times10^{-4}$ 1/ year	18 times
3.	Romania 45,5 N Latitude, 29 E Longitude.	M=6, H=15 km	≥10	2.2×10^{-4} 1/ year	22 times
4.	Bulgaria, 44 N Latitude, 25 E Longitude.	M=6, H=15 km	≥10	$3{,}1\times10^{-4}$ 1/ year	31 times
5.	Serbia, 43,5 N Latitude, 22 E Longitude.	M=5, H=10 km	≥10	$4{,}9\times10^{-5}$ 1/ year	4,9 times
6.	Turkey, 40 N Latitude, 30 E Longitude.	M=5, H=10 km	≥10	$2{,}4\times10^{-4}$ 1/ year	24 times
7.	Turkey, 42 N Latitude 35 E Longitude	M=6, H=15 km	≥10	$4{,}2\times10^{-4}$ 1/ year	42 times
8.	Turkey, 41,5 N Latitude 37 E Longitude,	M=6, H=15 km	≥10	1×10^{-5} 1/ year	-
9.	Black Sea, 42,5 N Latitude, 38 E Longitude.	M=7,8, H=10 km	≥10	-	-
10.	Turkey-Georgia, 41 N Latitude, 41 E Longitude	M=6, H=10 km	≥10	$1{,}1\times10^{-3}$ 1/ year	110 times
11.	Georgia, 42 N Latitude, 42 E Longitude.	M=6, H=10 km	≥10	$7{,}7\times10^{-4}$ 1/ year	77 times
12.	Azerbaijan, Georgia, Russia, 42 N Latitude, 47,5 E Longitude	M=6, H=10 km	≥10	$4{,}3\times10^{-3}$ 1/ year	430 times

13.	Russia, 44 N Latitude, 38 E Longitude	M=7, H=10 km	≥10	$1,9\times10^{-4}$ 1/ year	19 times
14.	Russia, Ukraine, 45 N Latitude, 36 E Longitude.	M=6,5, H=10 km	≥10	$2,95\times10^{-4}$ 1/ year	29,5 times
15.	Russia, Ukraine, 45 N Latitude, 35 E Longitude.	M=5,5, H=10 km	≥10	3×10^{-4} 1/ year	30 times

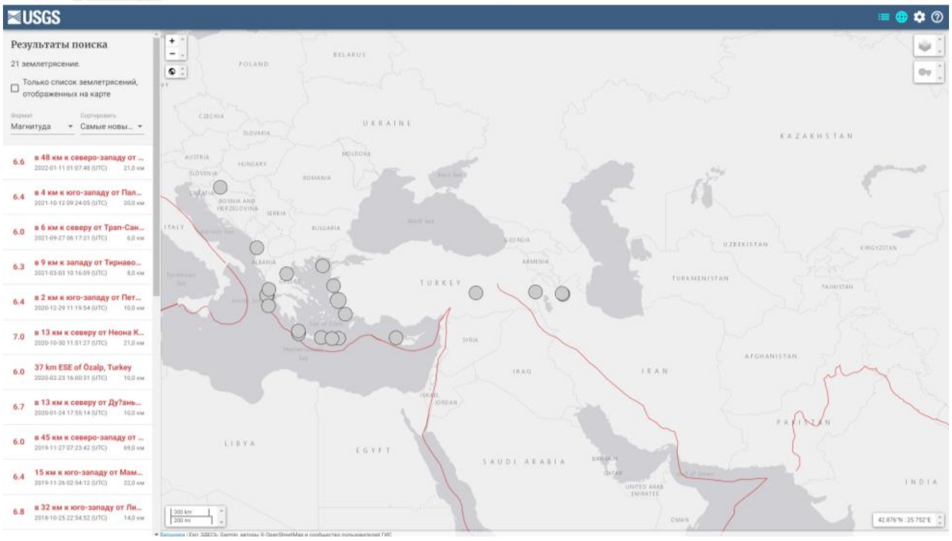

Figure 6: *Earthquakes with M≥6 occurred in the Black Sea-Caspian Sea region for the last 10 years (from data of the USGS).*

Fig. 6 shows that during the last 10 years in the Black Sea-Caspian Sea region under consideration the most earthquakes occurred in Turkey and the Balkans. In the Caucasian region the seismic energy did not strongly manifest itself during this period of time, that is why the threat of WHO triggering for Caucasian region still remains.

IV. Discussion

The proposed end-to-end individual seismic risk assessment technique for different stages of PES manifestation can be used both for one-time assessment of individual seismic risk and for its monitoring over time at all PES stages. Data in Table 1 and Figures 1 and 6 show that not all PES projections have materialized and that the risks to the population of the Black Sea-Mediterranean-Caspian Sea region exceed the normative value of 10-51/year, according to the authors. In order to clarify the values of individual risk for the territories of the Caucasus it is proposed:

- refine the maps of zones of increased seismic activity using complex precursors in the form of thunderstorm activity, atmospheric pressure drop, cloud portrait, seismic and geophysical data;
- to clarify the seismic resistance of typical buildings in the territories in question using the method of dynamic tests (proposed by the example of Derbent);
- to specify databases on buildings and population in the geoinformation system "Ekstremum" designed to calculate consequences of strong earthquakes;

- perform calculations of consequences and assessment of individual seismic risks (proposed on the example of Derbent).

The calculations performed on individual seismic risk assessment can be used for effective planning of measures for reduction of possible risks.

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