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SIMULATION-BASED INFORMATION SYSTEMS FOR MULTI-HAZARD RISK ASSESSMENT AND NEAR REAL TIME LOSS ESTIMATIONS DUE TO STRONG EARTHQUAKES

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Abstract

The paper addresses the questions most frequently raised by risk managers: what is the likely outcome (consequences) of future natural and technological disasters, as well a strong earthquake just occurred. It suggests simulation models and procedures for estimating the potential impact of negative events in terms of life and property losses. The paper is providing the results of multi-hazard and seismic individual risk assessment and mapping for the territories of the Russian Federation at national and regional levels with Extremum family systems’ application, as well as near real time damage and loss assessment due to strong earthquakes at global scale.

Introduction

Natural and technological disasters are becoming more frequent and devastating. Social and economic losses due to negative events increase annually, which is definitely dealt with evolution of society. In order to save lives and protect property against future events the urgent measures should be taken. Disasters’ preparedness of population and Civil Defense professionals, development of preventive measures plans, as well as rapid response systems should be improved. Assessment of loss due to earthquakes and other hazardous processes of natural and technological character are of primary importance in evaluating potential scope of the disaster just occurred as well as in estimating and mapping multi-hazard risk at different levels. The paper addresses the simulation models for shaking intensity distribution, damage to buildings and structures, number of fatalities and injuries, which are used in Extremum family systems assigned for these purposes, as well as procedures for multi-hazards risk assessment. It analyses the influence of uncertainties, as well as that of intrinsic methods applied, on the reliability of estimations obtained with the systems’ application.

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Simulation Models' description

The section describes the models for seismic hazard, vulnerability, damage and casualties estimates. All simulation models bring in their own uncertainties and propagate the uncertainties of the previous steps of the estimation procedure. Actually, the problems of accuracy are considerably more complex than it is suggested in the previous sentence; in addition, to the classical behavior of uncertain input data through each step of the procedure, the simulation models introduce biases of which influence on the final results is not easy to assess; this cannot be thoroughly discussed here.

Estimation of shaking field

Data about event source parameters are input for computation of probable shaking field, in terms of "intensity". Authors understand that the previous sentence could be very much misleading; by definition, intensity describes formally an observed state of a set of artifacts which have undergone damage caused by an earthquake; it cannot, *a priori*, be "computed"; furthermore, it takes conventional values in the form of integers (it is "scale"), a decimal value being meaningless (at the most, an observer can hesitate between two integer values to assign, what is sometimes rendered as a half-grade. The "intensity" referred to here is of somewhat different nature: it stems from a regression analysis between "true intensity" and measured acceleration (when available, which is not often the case); in a way, it can be considered as an interpolated value of acceleration between two consecutive "true intensities" empirically converted into accelerations. Authors follow the traditional way of expressing the shaking; no doubt that progresses are badly needed to improve the situation and think in terms of true acceleration responsible for the damage observed.

The formula used is taken from Shebalin (1968).

$$I = bM - \nu \lg \sqrt{\Delta^2 + h^2} + c \tag{1}$$

where Δ - epicentral distance (km); h - source depth (km); M - magnitude.

Coefficients in the formula are estimated taking into account empirical data. They are estimated by Shebalin and given for the former USSR regions in (New…, 1977).

More general generalization of attenuation law parameters for Europe are given by the report (Earthquake..., 1998). The coefficients proposed for the Southern and Northern parts of the Central and Southern Europe are listed in Table 1.

Table 1. Macroseismic field coefficients for the Central and Southern Europe by (Earthquake …, 1998)

Region	***b***	***ν***	***c***
Southern part $\varphi \le 47^\circ$ N	1.5	4.0	3.8
Northern part $\varphi > 47^\circ$ N	1.5	3.5	3.6

For other territories, these coefficients may be derived from statistical analysis of available data sets; one could alternatively use the average values: 1,5; 3,5; 3 proposed by Shebalin.

Vulnerability functions for buildings/ Fragility laws

In the present situation both concepts of fragility and vulnerability are used by authors. Vulnerability may be estimated through physical and economical domains. Physical vulnerability is an index, which characterizes the loss of functional properties of the considered structure. It may be estimated as a ratio between the expected number of damaged buildings of a certain type due to earthquakes with intensity I and total number of buildings belonging to this type. Economic vulnerability for buildings of different types is characterized by ratio between the cost of repair and the initial cost of construction (Larionov et al., 2003a, 2003b, 2006).

In the Extremum family systems the fragility laws are used for different building types classified according to MMSK-86 scale:

- buildings' types A1, A2 (from local materials);
- buildings' types Б, Б1, Б2 (brick, hewn stone or concrete blocks);
- buildings' types B, B1, B2 (reinforced concrete, frame, large panel and wooden);
- buildings' types C7, C8, C9 (designed and constructed to withstand the earthquakes with intensity 7, 8, 9)

The fragility laws are understood as the dependence-ships between the probability of buildings belonging to different types to be damaged and the intensity of shaking in grades of seismic scales. The laws are usually constructed on the basis of statistical analysis of strong earthquakes engineering consequences.

There are two types of laws: the probability P_{Ai} (I) of damage state not less than given value and probability P_{Bi} (I) of definite damage state. The normal law is used for construction the curve approximating the probability P_{Ai} (I). The hypothesis about the normal law was checked with application of Kolmogorov-Smirnov criterion.

When constructing the fragility law, it is taken into account that buildings may suffer after earthquake any damage state (from $d = 1$ up to $d = 5$), namely a building after earthquake may prove to be undamaged (event *B0*), to experience slight damage (event *B1*), moderate damage (event *B2*), heavy damage (event *B3*), to be partially destroyed (event *B4*), to be completely collapsed (*B5*). In order to estimate the parameters of the normal laws the representative statistical data set, which includes events occurred in the second part of XX – beginning of XXI centuries in Russia, Uzbekistan, Turkmenistan, Romania, Moldova, Armenia, Georgia and other countries, was used. The values of mathematical expectation *M* of earthquake intensity in grades of MMSK-86 intensity scale, which result in building damage state not less than given value, are given in Table 2. The values of mean square deviations of intensity vary from 0.4 up to 0.5.

Table 2. Averaged expected intensity of earthquakes in grades of MMSK-86 scale, which will result in different damage states of buildings

***Buildings types according to* MMSK-86**	***Buildings damage states d***				
	Light d=1	***Moderate d=2***	***Heavy d=3***	***Partially destroyed d=4***	***Completely collapsed d=5***
A1, A2	6.0	6.5	7.0	7.5	8.0
Б1, Б2	6.5	7.0	7.5	8.0	8.5
B1, B2	7.0	7.5	8.0	8.5	9.0
C7	7.5	8.0	8.5	9.0	9.5
C8	8.0	8.5	9.0	9.5	10.0
C9	8.5	9.0	9.5	10.0	10.5

When determining the probability P_{Bi} (I) of definite damage state the theorem about the total group of events is taken into account

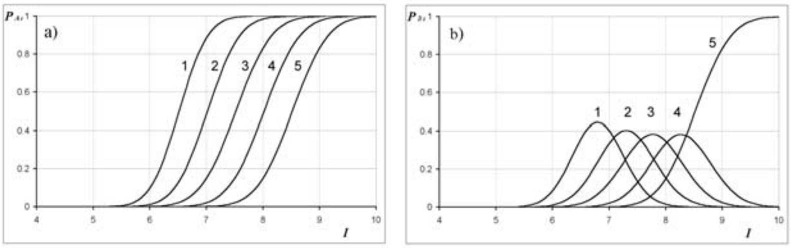
$$\sum_{i=0}^{5} P_{Bi}(I) = 1 \tag{2}$$

The probability P_{Bi} (I) of definite damage state of buildings is estimated by the relationship

$$P_{Bi}(I) = P_{Ai}(I) - P_{Ai+1}(I) \tag{3}$$

where P_{Ai} (I) - probability that buildings will suffer the damage state not less than state i; P_{Ai+1} (I) - probability that buildings will suffer the damage state not less than state i+1. The fragility laws for the buildings of *B* type, constructed with taking into account the characteristic normal laws parameters given in Table 2 and $\sigma = 0.4 - 0.5$ are shown in figure 1.

Fig. 1. Fragility laws for *B* type buildings (MMSK-86)
a – probability of damage state not less than given value; b – probability of definite damage state; 1, 2, 3, 4, 5 – buildings damage states



Building stock from earthquake prone area to another one is so varied (material, mode of construction) that one can wander about the validity of any averaged fragility laws (vulnerability functions). And, in principle, it is desirable to rely on regional data sets when constructing the fragility laws (vulnerability functions), but relevant data are not available for all earthquake prone areas either because engineering data on consequences of strong earthquakes are not accessible or simply do not exist.

In Table 3 the example of regional fragility law is given. The parameters of normal laws for the region around the lake Baikal, Siberia were estimated on the basis of data available in the Regional Scale of Seismic Intensity for this area (РШСИ-2000). The value of mean square deviations of intensity for all types of buildings is equal to 0.5.

Table 3. Averaged expected intensity of earthquakes in grades of MMSK-86 scale, which will result in different damage states of buildings

Buildings types according to РШСИ-2000	***Buildings damage states d***				
	Light d=1	***Moderate d=2***	***Heavy d=3***	***Partially destroyed d=4***	***Completely collapsed d=5***
A, *C5*	6.2	7.0	7.8	8.6	9.4
Б, *C6*	6.4	7.4	8.4	9.4	10.4
B, *C7*	6.7	8.0	9.1	10.1	11.0
C8	7.3	8.7	9.8	10.7	11.3
C9	8.3	9.5	10.4	11.2	11.5

Besides fragility laws (vulnerability functions) Extremum system simulation models allow to construct damage probability matrices for different buildings types also based on empirical data. The information about earthquake engineering consequences gained after separate events, as well as statistical data of international and regional seismic intensity scales may be used for estimating the probability of definite damage state. These matrices also should be of regional type in order to take into account the peculiarities of existing building stock for the country under consideration. The Table 4 shows the probabilities of damage states equal to 5, 4 and 3 estimated with different empirical data sets: extended statistical data about strong earthquakes consequences in CIS and other countries; empirical data in EMS-92 and information about the behavior of 32,548 buildings of 15 structural types gathered in 41 towns after the 1980 Irpinia earthquake (Chavez et al., 1998***)***.

The probabilities of damage state *d*=5 estimated with usage of EMS-92 scale and data set in Chavez et al. (1998) are less in comparison with the values based on extended data set for the events occurred in CIS and other countries. This fact gives evidence about more vulnerable building stock in the latter countries. The maximum deviation in probabilities to survive damage states *d*=5, 4 and 3 providing the same intensity reaches 40 %. Moreover the building stock is evolving (ageing, maintenance): monitoring is needed. In practice this is barely taken into account in computing the averages.

Table 4. Probabilities of definite damage states in the case of the event intensity *I*=8

***Buildings types according to* MMSK-86**	***Source of information about damage to buildings***								
	Reports and publications about events consequences in CIS and other countries			***EMS-92***			***Chavez et al., 1998***		
	***d*=5**	***d*=4**	***d*=3**	***d*=5**	***d*=4**	***d*=3**	***d*=5**	***d*=4**	***d*=3**
A	0.50	0.34	0.09	0.11	0.45	0.14	0.10	0.34	0.35
Б	0.20	0.37	0.30	0.00	0.10	0.32	0.01	0.34	0.20
B	0.02	0.14	0.34	0.01	0.05	0.14	0.00	0.13	0.13
C7	0.01	0.02	0.14	0.00	0.01	0.06	0.00	0.02	0.03
C8	0.00	0.01	0.02	0.00	0.00	0.00	0.00	0.01	0.00
C9	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00

Vulnerability of population/ Laws of earthquake impact

Vulnerability of population to seismic action of a given intensity is understood here as the ratio between the expected fatalities and the total number of persons living in a certain type of buildings. In order to estimate the mathematical expectation of fatalities and injuries within the built environment the laws of earthquake impact on population are used. They are understood as the dependence-ship between the probability to be killed or/and injured and the intensity of shaking in grades of seismic intensity scales.

The parametric laws of earthquake impact on people inside buildings are constructed on the basis of analysis of empirical data about social losses during past strong earthquakes with taking into account the theorem about the total group of events. When computing the laws, it is assumed that the event C_k (total number of social losses, irrevocable and sanitary losses) may occur providing that the building survived one of the damage states (at one of the hypothesis B_i forming the total group of incompatible events).

Fatalities and missing are referred to irrevocable losses. Sanitary losses include all people who need medical treatment. The sum of sanitary losses and irrevocable ones are called total losses. The structure of sanitary losses takes into account three level of impact: extremely heavy injured, heavy injured and slightly injured. Social losses are computed according to

$$P_{Ck}(I) = \sum_{i=1}^{5} P_{Bi}(I) \cdot P(C_k | B_i) \tag{4}$$

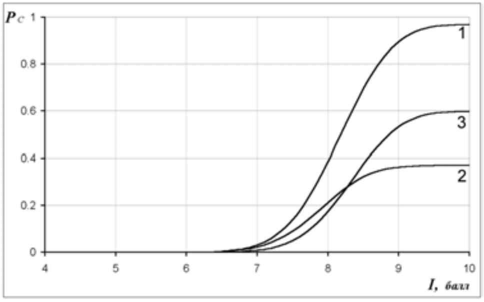
where $P_{Ck}(I)$ — probability of people to be impacted during the earthquake with intensity I; $P_{Bi}(I)$ — probability of definite i damage state of buildings providing the given value of earthquake intensity; $P(C_k|B_i)$ — probability of people to survive k level of impact under the condition that the building survived the damage state i. The values of $P(C_k|B_i)$ are obtained on the basis of processing of empirical data about social losses due to past events in the CIS and other countries during the last about 50 years (table 5).

Table 5. Probability of population to be affected for different damage states *d* of buildings

***Social losses C*$_k$**	***Probability of population to be affected at damage states of buildings***				
	Light d=1	***Moderate d=2***	***Heavy d=3***	***Partially destroyed d=4***	***Completely collapsed d=5***
Total	0	0.01	0.11	0.6	0.97
Irrevocable	0	0	0.02	0.23	0.6
Sanitary	0	0.01	0.09	0.37	0.37

The laws of earthquake impact on population inside buildings of *B* type, which are constructed with use of Table 6, are shown in fig. 2.

Fig.2. Laws of earthquake impact on people inside *B* type buildings: 1-total social losses (total number of casualties); 2- sanitary losses (injuries); 3- irrevocable losses (fatalities)



In Table 6 the probabilities of population to be affected against the seismic intensity *I*, which are obtained with usage of the equation (4) and Table 5, are shown.

While computing expected social losses the empirical data about the population migration during day time, as well seasonal variations should be taken into account.

Table 6. Probabilities $P_{Ck}(I)$ of population to be affected inside buildings of different types against seismic intensity

***Buildings types according to* MMSK-86**	***Social losses***	***Intensity in grades of MMSK-86 scale***						
		6	**7**	**8**	**9**	**10**	**11**	**12**
A	Total losses	0.004	0.14	0.70	0.96	0.97	0.97	0.97
	Irrevocable losses	0	0.05	0.38	0.59	0.6	0.6	0.6
Б	Total losses	0	0.03	0.39	0.90	0.97	0.97	0.97
	Irrevocable losses	0	0.01	0.18	0.53	0.6	0.6	0.6
B	Total losses	0	0	0.14	0.70	0.96	0.97	0.97
	Irrevocable losses	0	0	0.05	0.38	0.59	0.6	0.6
C7	Total losses	0	0	0.03	0.39	0.90	0.97	0.97
	Irrevocable losses	0	0	0.01	0.18	0.53	0.6	0.6
C8	Total losses	0	0	0.004	0.14	0.70	0.96	0.97
	Irrevocable losses	0	0	0	0.05	0.38	0.59	0.6
C9	Total losses	0	0	0	0.03	0.39	0.90	0.97
	Irrevocable losses	0	0	0	0.01	0.18	0.53	0.6

Individual risk assessment and mapping at different levels

The above described simulation models are used within the framework of the Extremum family systems for estimating the individual seismic risk R_s or the probability of death (or injuries) due to possible earthquake within one year in a given territory. Seismic risk may be determined through mathematical expectation of social losses $M(N_j)$ with taking into account the number of inhabitants *N* in the considered settlement and probability of seismic event *H*

$$R_s = H \cdot V_s\,(I) = H \cdot M(N\ )/N \tag{5}$$

where $V_s(I)$ – vulnerability of population for the considered settlement; *H* – probability of seismic event per one year; *N* – the number of inhabitants in the considered settlement.

The mathematical expectation of social losses $M(Nj)$ for the considered settlement taking into account inhabitant migration in the buildings of *j* type during the day and night is determined by equation

$$M(N_j) = \sum_{j=1}^{n} \iint_{S_c} \int_{0}^{24} \int_{I_{\min}}^{I_{\max}} P_{Cj}(I) \cdot f(x, y, I) \cdot \Psi_j(x, y) \cdot f(t)\,dI\,dt\,dx\,dy \tag{6}$$

where $I_{\min}$ и $I_{\max}$ – maximum and minimum possible earthquake intensity; S_c – settlement area; n – number of considered building types according to MMSK-86 scale; $P_{Cj}(I)$ – probability of fatalities and injuries under the condition of damage to buildings of j type due to earthquake with intensity I; $\psi_j(x,y)$ – density of population distribution within the considered area in buildings of j-type; $f\,(x,y,I)$ – density function of earthquakes' intensity probabilities within the unit area with coordinates x , y; $f(t)$ – function obtained on the basis of statistical analysis of data on population migration during 24 hours.

The multi-hazard individual risk R_e may be estimates as

$$R_e = 1 - \prod_{i=1}^{n} (1 - R_{ei}) \tag{7}$$

where n — number of considered emergency situations of natural and technological origin; R_{ei} — individual risk due to i-th emergency situation.The individual risk computations with simulation models' application may be carried before and just after the event in near real time. The reliability of loss and risk estimations strongly depends on different issues, but the most important ones are the databases on population and building stock distribution, as well as regional vulnerability functions of various elements at risk and regional shaking intensity attenuation laws (Bonnin et al., 2002a, 2002b, 2004; Chen Yong et al., 2001; Frolova et al., 2006). When computations are done at different levels: facility level, urban, regional, country or global one, the proper databases should be developed taking into account the end user requirements about the details of expected results.

Examples of seismic and integrated risk assessment and mapping at national and regional levels with System Extremum application are shown on fig. 3 and 4. In order to make computations of individual seismic risk for the whole Russian Federation territory and the Krasnodar area a lot of data about population distribution and existing building stock was compiled and analyzed. Table 7 presents the general information about existing building stock in the Krasnodar area.

Table 7. Averaged characteristics of existing building stock for the Krasnodar area

Building type (MMSK-86)	***City model***		***Town model***		***Village model***	
	Portion	***Height, m***	***Portion***	***Height, m***	***Portion***	***Height, m***
A	0.33	6	0.43	4	0.58	4
Б	0.45	15	0.48	6	0.39	6
B	0.14	21	0.08	9	0.02	7
C7	0.08	16	0.01	12	0.01	10

Class and location of settlements were taken from Russian topographic maps of scale 1: 200 000 published by MTS, 1970-1999, and verified according to the administrative maps of Russian Federation of scale 1:500 000…1:3000 000. On the whole the information about 250 000 cities/ towns and villages were used for risk computations at national level.

The information about seismic hazard was taken from the review maps of seismic zonation of the Russian Federation territory OSR-97A, B, C. The maps show the seismic intensity I which may occur in a given area within the time interval equal to 50 years with probability of exceedence equal to 10% (OSR-97A), 5% (OSR-97B) and 1% (OSR-97C).

The obtained values of individual multi-hazard risk for the Russian Federation (fig. 3) vary from negligible ones up to $50.0 \bullet 10^{-5}$ and higher.

Fig. 3. Zonation of the Russian Federation territory according to the level of multi-hazard risk;
risk R_e , 10^{-5} 1/year categories: 1- more than 50; 2 – 20 up to 50; 3 – 5 up to 20; 4 – 1 up to 5; 5 – 0.5 up to 1; 6- 0.2 up to 0.5; 7 - 0.1 up to 0.2; 8 –less than 0.1. Values of risk for the cities with population more that 50 000 people, R_e , 10^{-5} 1/year: 9 – more than 50; 10 – 20 up to 50; 11 – 10 up to 20; 12– 5 up to 10; 1 up to 5; 13 – 1 up to 5; 14 – 0,5 up to 1; 15 - less than 0,5. Number of inhabitants: 16 –1,000,000 and more; 17 - 500,000 up to 1,000,000; 18 – 200,000 up to 500,000; 19 – less than 200,000

The following risk R_e , 10^{-5} 1/year categories are identified: extremely high (> 50); rather high (20-50); high (10 – 20); average (5 – 10);- moderate (1 – 5); insignificant (0,5 –1); low (< 0,5). The highest values of risk are typical for settlements in Sakhalin, Kuril Islands, Kamchatka, near Lake Baikal, Altai-Sayan region and Northern Caucasus. In these regions the main contribution to risk value is made by natural disasters. The highest values of risk due to technological accidents are typical for cities: Bratsk, Novokuzketsk, Yurga, Kemerovo, Norilsk, Dzerzhinsk, Orsk, Tol'yati, Nizhnij Tagil, Pervouralsk, Magnitogorsk, Chelyabinsk. In these regions the special measures should be implemented to reduce the risk level.

The results of seismic risk computations for the Krasnodar region are presented in fig.4 by signs (circles of different size and color) for cities and by hypsometric layers for small settlements with number of inhabitants less that 1,000 people.

Fig. 4. Zonation of the Krasnodar area according to the level of individual seismic risk taking into account secondary technological accidents;
risk R_e , 10^{-5} 1/year categories: 1- more than 30; 2 – 25 up to 30; 3 – 20 up to 25; 4 – 15 up to 20; 5 – 10 up to 15; 6- 5 up to 10; 7 - 1 up to 5; 8 – 0.5 up to 1; 9 - less than 0.5. Values of risk for the cities with population more that 50 000 people, R_e , 10^{-5} 1/year: 10 – more than 30; 11 – 25 up to 30; 12 – 20 up to 25; 13– 15 up to 20; 14 – 10 up to 15; 15 - 5 up to 10; 16 - 1 up to 5; 17 – 0,5 up to 1; 18 - less than 0,5. Number of inhabitants: 19 – more than 500,000; 20 - 100,000 up to 500,000; 21 – 50,000 up to 100,000; 22 – 10,000 up to 50,000; 23 – 2,000 up to 10,000; 24 – 1,000 up to 2,000

Obtained values of seismic risk for the Krasnodar area (fig. 4) vary from negligible values up to rather high ones equal to $40.2 \bullet 10^{-5}$. The high values of risk are obtained for the Novorossijsk city, Tuapse and Lazarevskoe towns, as well as for Krasnodar city, Sochi and Adler towns. On the whole for more that 40 % of the Krasnodar region territory the value of seismic risk computed taking into account the secondary technological processes exceeds value equal to $1.0 \bullet 10^{-5}$.

Earthquake loss estimations in "emergency mode" at global scale

Different Extremum family systems are used for expected loss assessment due to strong earthquake at global scale. Since August, 2000 the system version is used in order to provide quick information on damage and casualties assessment of strong earthquakes all over the world within the framework of EUR-OPA Major Hazards Agreement Program EDRIM (Electronic Discussion for RIsk Management).

Procedure of expected damage and loss assessment in "emergency mode" includes:

1. The information about the earthquake parameters (origin time, epicenter coordinates, depth, magnitude) is received by e-mail messages or taken automatically from Web sites of Seismological Surveys: Geophysical Survey of Russian Academy of Sciences (GS RAS), European Mediterranean Seismological Center (EMSC), National Earthquake Information Center of USGS (NEIC), and occasionally national agencies, such as Kandilli Observatory and Earthquake Research Institute (KOERI), Japan Meteorological Agency (JMA), Japan Weather Association (JWA) and others;

2. Computations of expected damage extent, social and economic losses due to earthquakes and identification of the effective response measures;

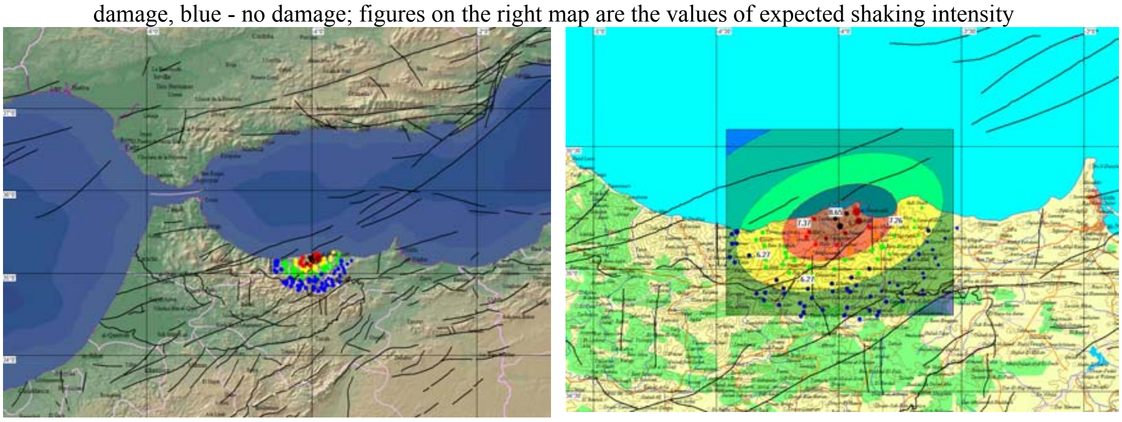
3. Expert estimation of the obtained results with the knowledgebase about past events application;

4. Taking a decision about expected consequences estimation;

5. Dissemination of messages about expected damage and losses.

The results of computations are usually presented as maps and tables, where estimations of expected number of fatalities, injuries and homeless are given for the whole stricken area and for each settlement. Figure 5 shows maps with the results of expected damage and loss computation for the earthquake occurred on February 24, 2003 in Morocco with Extremum System application. By dots of different size and color are shown the settlements in the stricken area; the dot size stands for the number of inhabitants, the dot color stands for the average damage state of the buildings. In the given example the computations were made for the following event parameters: Latitude - 35,190N; Longitude - 3,996W; Depth - 2 km; Magnitude - 6,1 (Taj-Eddine Cherkaoui et al., 2004).

Fig. 5. Results of possible losses assessment due to February 24, 2004 earthquake in Morocco in different scales; dots are settlements in the stricken area; colour of dots stands for the average damage state of building stock: black -total collapse, brown - partial collapse, red - heavy, yellow -moderate, green - slight damage, blue - no damage; figures on the right map are the values of expected shaking intensity



The results of expected damage and loss estimations strongly depend on the input event parameters determined by Seismological Surveys in "emergency" mode. Figures 6a, b show the patterns of expected damage distribution in the case of the Bam earthquake occurred in Iran on December 26, 2003, which were obtained with the using NEIC data (fig. 6a) and IIEES data (fig. 6b). Underestimation of expected damage was related mainly with unreliable depth determination (it was given as 33 km by GS RAS and NEIC and revised on December 27, 2003) and with scatter in event location (Table 8). According to the information published on July 22, 2004 at the ***ReliefWeb*** site the Iranian authorities revised the number of dead from December 26 quake, which Bam officials had earlier said killed 43,000. The event location made by IIEES (assumed to be the most accurate) and focal depth estimation by Reconnaissance Team (Eshghi et al., 2003) allowed to obtain the estimation of expected number of casualties close to reported one (Table 8).

Table 8. Expected consequences due to the Bam earthquake on December 26, 2003

Survey	***Coordinates***	***M***	***h, km***	***Expected fatalities***	***Expected injuries***
NEIC	58.27 N; 29.01 E	6.7	33	18-221	110-1,008
NEIC, Significant Earthquakes	58.311 N; 28.995E	6.6	10	5,538-22,337	14,933-40,904
EMSC	58.34 N; 29.05 E	6.8	30	1,201-6,939	2,751-18,661
GS RAS	58.38 N; 29.24 E	6.8	33	417-3,168	1,247-10,776
IIEES	58.38 N; 29.08 E	6.5	13.2	6,795-25,035	19,085-38,122
IIEES	58.38 N; 29.08 E	6.5	8*)	11,022-35,394	33,067-40,831

*) (Eshghi. et al., 2003)

Fig. 6a. Results of possible losses assessment due to December 26, 2003 earthquake in Iran with usage of NEIC event parameters

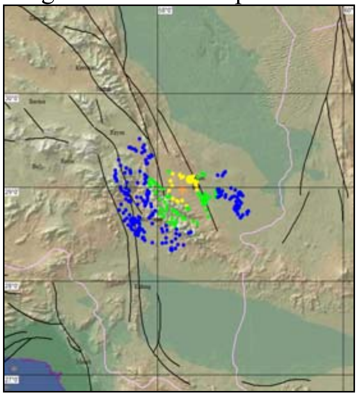
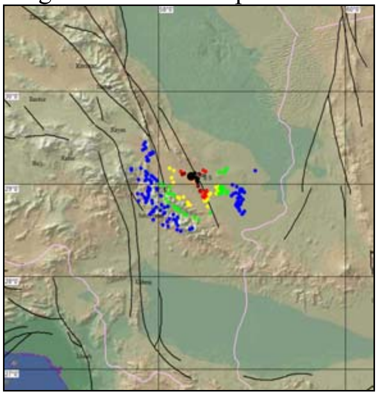


Fig. 6b. Results of possible losses assessment due to December 26, 2003 earthquake in Iran with usage of IIEES event parameters



Taking into account the scatter in expected number of casualties obtained with using different event parameters determined by Seismological Surveys in "emergency" mode, the role of experts should be mentioned. Expert knowledge and/or knowledgebase about past events in the stricken area may help to make a proper choice between the estimations on expected damage and loss obtained with the Extremum System application.

The analysis of results of computation on expected damage and loss by expert team definitely allows to increase the reliability of estimations, which will be transferred to decision makers. But it will take additional time and may result in about one hour delay.

Besides the errors in event parameters determinations by Seismological Surveys, there are other factors which influence on reliability of expected damage and loss assessment in "emergency" mode with the Extremum System application. Between them the main factors are the following:

- completeness and reliability of databases on elements at risk (population and built environment) and hazard sources;
- reliability of vulnerability functions for different elements at risk due to earthquakes and other secondary hazards;
- lack of access to confidential sources of information. damage and casualties to be estimated with the error, which does not exceed 60%.

Some of these factors may be taken into account at the expense of the System calibration with usage of knowledgebase about well documented past strong earthquakes mentioned before (Frolova et al., 2003a, 2003b; 2006) and high-resolution space images application in order to verify the data on buildings' inventory in earthquake prone areas. The only factor, which can't be compensated by the system calibration, is the influence of the discrepancies of events location by different Alert Seismological Surveys. More than six years experience of the Extremum family Systems' operation showed that in practice one of the Surveys provides the input data, which allows expected damage and casualties to be estimated with the error, which does not exceed 60%.

Conclusions

The present paper gives the description of simulation models for shaking intensity distribution, seismic vulnerability of different elements at risk, as well as methodological procedures for seismic and multi-hazard risk assessment with application of the Extremum family systems.

The examples of the System application for different purposes: near real time damage and loss assessment at global scale, as well as multi-hazard risk assessment for the Russian Federation territory and seismic risk estimation for the Krasnodar region taking into account technological accidents triggered by strong earthquakes are given.

On the whole, application of Extremum family systems for expected loss and risk assessment at different levels showed good and less good things for many reasons. In future many refinements should be introduced in order to avoid existing limitations in simulation models and databases on population and built environment distribution.

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