

CALIBRATION OF REGIONAL VULNERABILITY FUNCTIONS BY APPLYING EARTHQUAKE EVENTS DATABASE

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ABSTRACT. The paper describes the structure and content of the Information System database containing information on earthquake events, which is developed and supported within the framework of computer support for the EMERCOM of the Russian Federation. The database is assigned to provide analytical support for decision making in case of an emergency situation, including tools for mathematical simulation of hazardous excitation, the response of elements at risk to excitation and loss generation. The calibration procedure of the earthquake vulnerability functions for buildings and structures using the database with descriptions of events is presented. The calibrated functions of earthquake vulnerability for buildings of different types are applied to provide an acceptable accuracy of situational assessments for the case of a strong earthquake. The examples of earthquake damage estimations for the test site in Siberia showed that region-specific parameters in the vulnerability functions yield more reliable results to estimate possible damage and losses due to a large earthquake. For Irkutsk City, the estimates of the numbers of heavily damaged and completely collapsed buildings obtained when using different sets of parameters for vulnerability functions differ by 30%. Such difference in damage estimates can significantly affect the plans for rescue and recovery operations. The conclusion is made about the advantage of the calibrated functions application for near real-time damage and loss assessment due to strong earthquakes in order to ensure population safety and territory sustainable development.

KEY WORDS: earthquakes, reliability of near real time loss estimates, impact database, calibration of mathematical models for vulnerability of buildings and structures

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INTRODUCTION

In Russia, as in the world in general, great attention is paid to the protection of people from natural and manmade disasters within the framework of the Sendai Framework for Disaster Risk Reduction 2015–2030 (<https://www.unisdr.org/files/43291.pdf>). Earthquakes, their secondary environmental effects (<https://www.isprambiente.gov.it/files/progetti/inqua/esi-eee-volume-april-2012.pdf>) and manmade phenomena are the most frequent factor to cause casualties and considerable economic losses. According to the statistical data supplied by international agencies and reinsurance companies, there is a growing

number of natural disasters and increasing associated economic and social impact due to uncontrollable urbanization of territories and an insufficient amount of prevention measures. According to the data supplied by the Centre for Research on the Epidemiology of Disasters (<http://www.emdat.be>), the years 1900–2015 saw an increasing rate of earthquake disasters and associated social and economic losses. The rate of casualties varies over the years in a periodic manner, peaking at the earthquakes in China (1976), Indonesia (2004), and in Haiti (2010). Earthquakes and associated manmade accidents and environmental effects continue to be the leading events in terms of casualties.

The world statistics of casualties and injured due to strong earthquakes shows that more than a half of all people under collapsed buildings (55%) died during the first three days (Goncharov et al. 2009). The first six hours are fatal for 60% of those who have suffered heavy injuries critical for survival. The number of casualties can be considerably reduced by timely and appropriate measures by rescuers (Aleksandrov et al. 2019). Fast and reliable information on a situation is necessary for making proper decisions about search-and-rescue operations and measures to be taken to provide humanitarian aid during the first hours following an event. In Russia, as in many other countries worldwide, a near real-time reliable forecasting of losses is based on the use of information systems (IS) such as the Automated Information Management System of the Russian Unified Emergency Prevention and Response System, the Russian abbreviation to be used in what follows being AIUS RSChS (Izmalkov 2017a, b; Kachanov et al. 2011; 2014). The efficiency of an IS is supported by high reliability in the fast prediction of the current situation based on data contained in the AIUS RSChS database of events. These data are used to calibrate the software that is employed in the assessments of situations, including models for the behavior of various buildings under seismic excitation. It is supposed that timely and reliable estimates of possible losses accelerate the response of decision making and reduce the time people stay in the hit zone, which allows to reduce the losses.

We provide a brief description of the structure and contents of database on events as recorded by the Ministry of the Russian Federation for Civil Defence, Emergencies and Elimination of Consequences of Natural Disasters (EMERCOM) using the AIUS RSChS. The procedure for applying the database to calibration of an earthquake vulnerability model and examples to illustrate the enhancement of earthquake-related loss assessment based on calibrated models are given.

A BRIEF DESCRIPTION OF THE DATABASE ON EVENTS RECORDED BY AIUS RSChS

The database that stores descriptions of events is part of the AIUS RSChS data storage that is developed and supported within the framework of computer support for the EMERCOM of the Russian Federation. For instance, for earthquakes, the information includes magnitude, epicenter coordinates, source depth, seismic intensity, macroseismic data, as well as resources and forces used for the response. In addition to the data storage, the AIUS RSChS also

includes software that consists of numerous units and interfaces. The development of this system relied on using Web-technology from Microsoft, in particular «.NETCORE and C #» (https://docs.microsoft.com/ru-ru/dotnet/core) (Izmalkov 2017a, b).

The database application fields are the following:

- storage and structuring of the documented data on disaster sources and elements at risk, for instance, information about residential buildings inventory;
- data support for forecasting the level of hazard and risk, as well as for preparing warnings, including those disseminated by mass media;
- storage of data acquired from recording the events that have been classified as emergency situations;
- data provision for the analytical support of decision making in case of an emergency situation, including tools of mathematical simulation of hazardous excitation, the response of elements at risk to excitation and loss generation;
- data provision for risk assessment and identification of risk zones;
- data provision for preparing reports on the situation, weather conditions, forces and equipment involved, as well as losses.

The generalized AIUS RSChS block diagram (Fig. 1) includes principle functional units, the data storage, and a user interface, as described in detail by Kachanov et al. (2011; 2014). The principle units are «Inventory», «Analytics» and «Operational management». The names of the units display their functions; description of units is supplemented by input and output information.

The «Analytics» unit contains mathematical models for the main types of technological accidents and natural hazards, including earthquakes and secondary processes. In the case of earthquakes, the software of the unit allows to simulate shaking intensity distribution, behavior of buildings and population, resources and forces needed for rescue and other urgent operations. The computations may be made just after the event, as well as for expected future «scenarios». The models are specific in that they are required to have high response speeds to input the data and the forecasting results have to be protected from the influence of possible considerable uncertainties. The uncertainties in input data arise from the estimation of parameters, their measurement, and transmission (Frolova et al. 2018).

An acceptable accuracy for the simulation results is achieved by calibrating the mathematical models in the «Analytics» unit specifically to a location of interest. Areas are mapped, and for each area there is a specific set of calibration parameters in the mathematical models. For example, for the shaking intensity

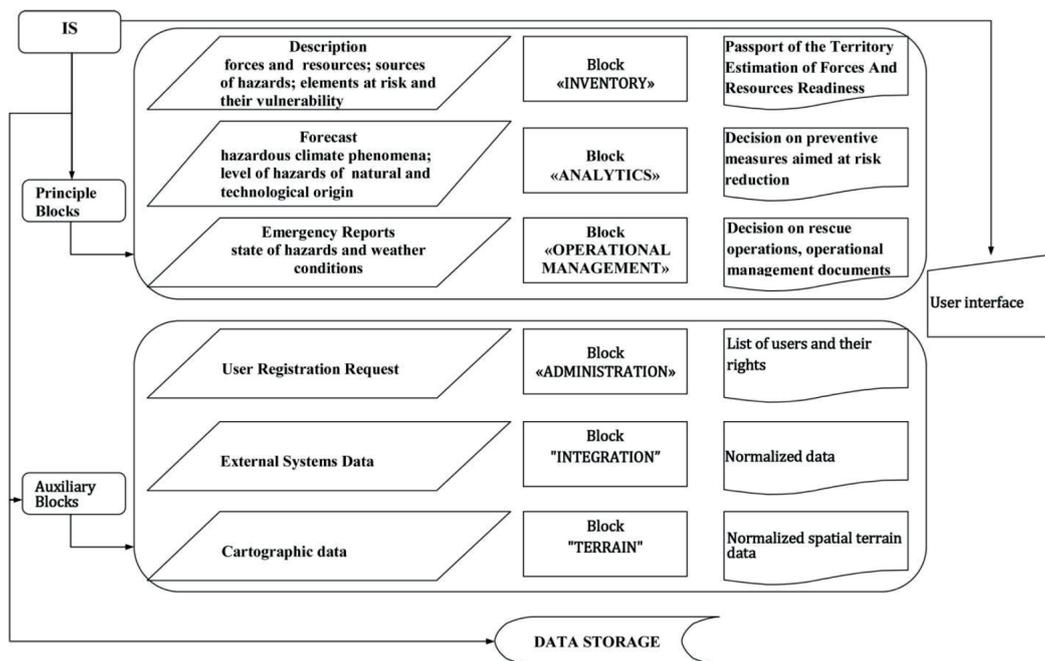


Fig. 1. Structure of EMERCOM Information System

simulation model these parameters are: regional coefficients in the Shebalin macroseismic field equation (Shebalin 1977); the orientation of the elliptic isoseist axes; the ratio k of the major and minor axes of macroseismic field ellipse (Frolova et al. 2019). The calibration of this kind satisfactory mimics learning processes for artificial intelligence systems. After calibration, any mathematical model that is implemented as a software module first determines the area of its calibration and retrieves the values of area-specific calibration parameters. The next step is the assessment itself.

All area-specific calibration parameters specific to areas and software modules are stored in the AIUS RSChS storage. Figure 2 shows the structure of the storage and the locations of the tables that contain calibration data in this structure.

The thicker line in Fig. 2 indicates the «Database with descriptions of events» and databases with «Zones with stable calibration parameters of mathematical models». These zones are formed during the calibration of the mathematical models. Each zone has its own mathematical model and its own set of calibration parameters.

It should be noted that the description of seismic events has some features that are important for calibrating simulation models used to assess earthquake-related losses during different phases of the simulation following the SP 322.1325800.2017 «Buildings and structures in seismic region. Rules of inspection of consequences of the earthquake» approved by the Ministry of Construction of Russia

(<https://files.stroyinf.ru/Index2/1/4293739/4293739217.htm>).

The structure of the tables with descriptions of seismic events is displayed in Fig. 3. A structured description of a seismic event can be accompanied by various appended unstructured information like maps, tables, photographs, and other documents. The calibration of a mathematical model for predicting the behavior of various buildings is based on data related to observed damage (Berzhinski et al. 2008, 2009; Berzhinskaya et al. 2009) in the form of damage tables.

When a strong earthquake is in question, the records in the damage table (Fig. 3) can be supplemented with the following materials of field observations and their analyses:

A map of observed macroseismic effects where the isoseismals show the area subject to shaking of intensity 6, 7, 8 or greater on the MMSK-86 scale (Shebalin et al. 1986);

photographs of damage inflicted to buildings of various types; summarized tables of macroseismic effects at population centers based on a variety of factors, including the behavior of buildings, human response, and the state of household objects;

updated information on the condition of residential buildings, on the numbers of residents in buildings of various types (type of building, total and residential area, number of residents, construction year, the degree of wear, and so on) (Berzhinski et al. 2008, 2009).

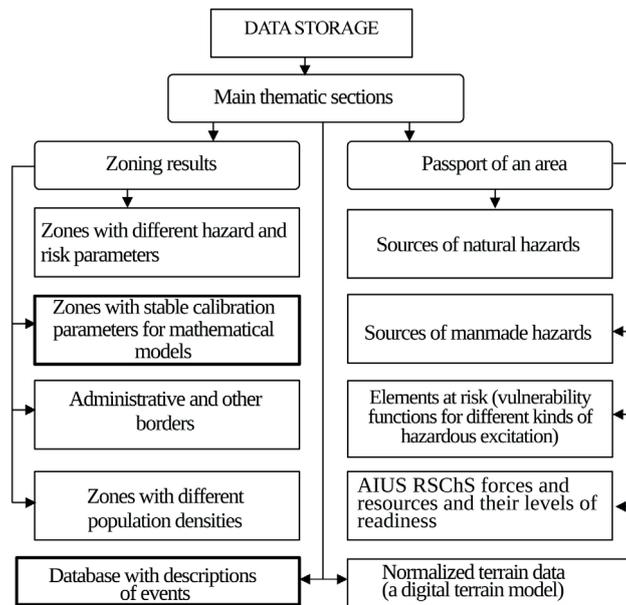


Fig. 2. The structure of the AIUS RSChS storage

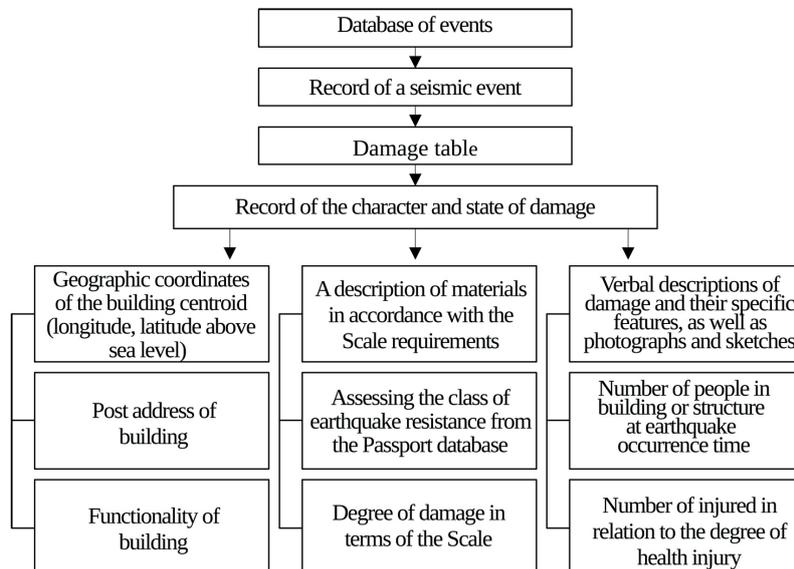


Fig. 3. The structure of tables with descriptions of events in the data base of events

CALIBRATION PROCEDURE OF THE EARTHQUAKE VULNERABILITY FUNCTIONS FOR RESIDENTIAL BUILDINGS

In this section, we discuss the calibration procedure for the earthquake vulnerability functions of buildings and structures using the database with descriptions of events. This procedure requires specifying the form of mathematical vulnerability model (function) used in a computer simulation.

The last decades saw great effort devoted to the development of earthquake vulnerability models. One of the key papers reviewing the methodologies over the last 30 years was written by Calvi et al. (2006). The number of types and forms for the representation of these functions as reported in the literature is steadily growing. The earliest study that proposed vulnerability matrices was (Martel 1964). These were later modified by Whitman (1973). Boore et al. (1993) specified a vulnerability function for discrete values of earthquake intensity *I*. All works usually adopt intensity *I* as a parameter to be related to damage *d* using a variety of approaches. This is also the case in later publications, e.g., (Braga et al. 1982; Spence et al. 1992; Di Pasquale et al. 2005). Work, done for national and international projects resulted in the development of an earthquake vulnerability model in which the state of damage is a function of both intensity and dynamic and spectral ground motion parameters (Lumantarna et al. 2014; Martinis et al. 2018; Yepes-Estrada et al. 2014; Xin et al. 2019). Taking into account the dynamic and spectral parameters of ground motion when constructing a vulnerability model allows to avoid the contradiction in the fact that the same measure, namely the observed effect, is used both for cause and consequences. Nevertheless, the use of vulnerability functions with MMSK-86 intensity *I* as input and the state of damage *d* as output based on the same scale remains rather popular today (Berzhinski et al. 2008; 2009a; 2009b; Zaalishvili et al. 2019). The difference between the input and the output is that the input is found by simulating the macroseismic field based on the laws that govern the propagation of ground motion, while the output quantity is found from physical laws that govern the excitation of buildings

and structures due to ground motion. It should be noted that the measure in both of these cases is a scale, a table consisting of two columns, with the one being intensity grade *I* and the other the observed impact, including the reported descriptions of various state of damage *d* for buildings (objects) and structures. The scales consider combining buildings (objects) according to parameters that affect the vulnerability to produce vulnerability classes. This combination of objects of different designs into classes is convenient for large scale assessments of earthquake impact. The combination results in individual properties of objects being replaced with averaged values that characterize a class, while the deviations from the average are random. This allows to reduce the number of vulnerability functions, making it equal to the number of classes. The parameters that vulnerability functions involve vary from class to class, as well as from one area to another. The sets of vulnerability functions chosen to serve for specific regions are referred to here as regional families characterized by sets of regional parameters. The use of regional parameters considerably reduces the deviation of properties for each object from the value that is typical of the appropriate class, thus enhancing the accuracy of the damage assessment.

An analysis of various ways to describe the relationship between felt intensity and the corresponding response of elements at risk has yielded main features of the vulnerability model. Each set of same-type elements has a corresponding unique vulnerability model of its own. These elements and the relationship between them are displayed in Fig. 4.

In the analysis of this procedure, the main factors that generate the various vulnerability functions are the following: the type of input data; the manner in which the functional relationship is specified; and the form in which the result is displayed. Objects or elements at risk are generally combined into classes based on similarities among the properties that characterize their vulnerability. In that case, each individual object, assuming that it does belong to a certain class, is assigned by the vulnerability properties of that class. Descriptions of vulnerability classes can

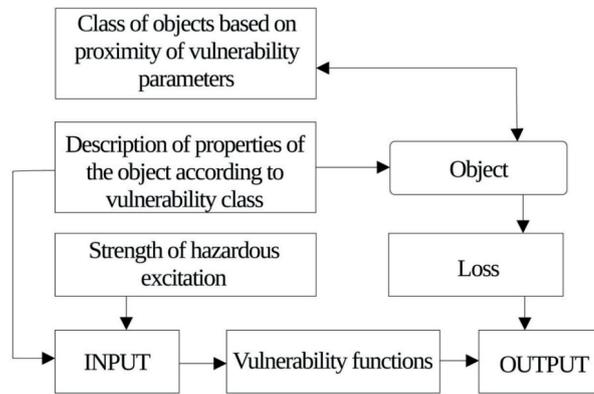


Fig. 4. The elements of the vulnerability model

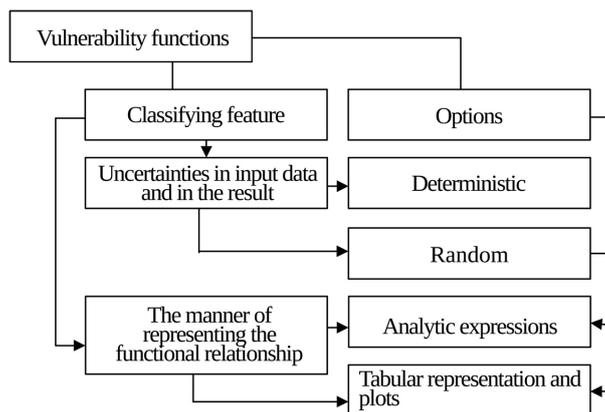


Fig. 5. The main classification parameters for vulnerability functions

be found in the scales due to (Shebalin et al. 1986; European... 1993; Sherman et al. 2003). The observed damage to a building may be expressed in different terms, but more often it is classified according to the rules specified by seismic intensity scales.

Figure 5 shows classification parameters for the vulnerability functions that are most frequently encountered in the literature.

Figure 5 shows the two main classification parameters that include the degree of uncertainty in input and output data, as well as the way the functional relationship is specified. It should be noted that random functions are used more frequently. The analytical and tabular forms of presentation are equally frequent.

The main difference between vulnerability functions consists in the way we represent the intensity-loss relationship. Vulnerability functions may be deterministic ones that use average values of the arguments, or probabilistic functions where, given values of the argument and function, we specify and/or calculate the parameters of the distribution law of random variables.

Arguments of a vulnerability function and the results can both be random. Random variables can be represented as either discrete or continuous values. Each individual case has its own distribution functions to describe the properties of discrete and continuous random variables. The probabilities of discrete random variables are usually specified in tabular form, while the probabilities of continuous random variables are specified in analytical form, with the Gauss distribution as one of the most frequent options (Aleksandrov et al. 2019).

The AIUS RSChS system contains a function of earthquake vulnerability for objects, which uses random intensity as input. The vulnerability function may be presented as a table with two fields of input. The table defines the relationship between the probability for an object to receive a certain state of damage d and an intensity I . The intensity I resulting in a state of damage d is interpreted as a continuous random variable that obeys the Gauss distribution with specified mean and variance. The intensity I for the location of an object found from Shebalin's formula (Shebalin 1968) is received by the vulnerability function as the mean and by the table where the second input is the class of vulnerability for the object. The output consists of pairs of values, characterizing the state of damage d and its probability. The first step in the calculation uses a list of pairs with all possible states of damage d and their probabilities. The pair with the highest probability is selected from the list. The state of damage d is used as the expected damage in subsequent calculations. In case the object is a block of buildings or a residential area of a population center with a uniform density of urban development rather than an individual building, the state of damage d is interpreted as the proportion of the buildings that have suffered the associated state of damage.

The calibration of a vulnerability function is limited by calculation of the mean and variance for the intensity I , which provides the most realistic estimate of the expected state of damage d for buildings that have been classified to a certain vulnerability class. The mean and variance are estimated using maximum likelihood method in relation to computed values and the data contained in the AIUS RSChS data base.

The calibration of a mathematical vulnerability model is made taking into account the relationship between the parameters in the Gauss distribution and the geographic area, as well as the boundaries to the zones where the same calibration parameters are used.

The calibration procedure is as follows. At the first step, the boundary of the area is specified depending on the properties of the used construction materials and the designs of structures, which are determined by the geographic location of the area, the level of earthquake hazard, and the level of its economic development. Next, the data related to the engineering impacts of earthquakes is collected. For each area it is necessary to have samples of estimated states of damage d with specified values of earthquake resistance of buildings and earthquake intensity I . The samples must be representative to ensure an unbiased estimate of the parameters in the Gauss distribution. This method requires that the sample mean is used as an estimate of the mathematical expectation, while the variance is determined using an unbiased estimator of the sampling values.

It can thus be said that in order to calibrate the mathematical model of earthquake vulnerability it is first necessary to obtain sufficient statistical material, which should include a number of records, which can be considered representative for the number of buildings and structures in the area subject to earthquake impact.

The more diverse are the structures in an area, and the higher the level of earthquake hazard, the greater will be the number of records required for the damage tables. The number of records on same-type buildings belonging to a certain vulnerability class affects the accuracy of the parameter estimates in a family of earthquake vulnerability functions. Nevertheless, the analysis of data on the impacts of strong earthquakes in Russia and worldwide has shown that, in spite of considerable economic and social losses, for some regions there is no exhaustive information on high states of damage d . When such cases are encountered, it becomes necessary to search for analogous regions where the impact of disastrous earthquakes has been recorded and stored with a high level of detail. The AIUS RSChS includes the possibility of record the events and produce the damage tables for any location worldwide.

In the next section, we are going to show how a database containing calibration parameters can be used in the calculating module to simulate the behavior of buildings in order to provide acceptable accuracy in situational assessments in case of a strong earthquake.

USING REGIONAL VULNERABILITY FUNCTIONS TO ENHANCE ACCURACY FOR BETTER LOSS ASSESSMENT

This section presents the results of a comparison between the earthquake impacts based on two sets of vulnerability functions; the first set was obtained through calibration, which was done following the rules given in the preceding section, while the second set consisted of generalized vulnerability functions based on extensive data on the engineering impact of earthquakes in a number of countries. The first set was applied to the test region, while the other can be used for any location in the seismic regions worldwide (Frolova et al. 2011).

The test region covers the seismic region of Baikal and Transbaikalia, which includes the large social and industrial facilities of Irkutsk Oblast, the Republic of Buryatia and adjacent areas (Fig. 6). From the calibration results the values of the regional parameters for vulnerability functions were obtained in accordance with the regional scale (Sherman et al. 2003). The scale incorporates seismological, engineering-geological, and climate-controlled construction features of the region (Berzhinski 2001). In terms of seismic zonation, the test region includes the Baikal Rift Zone which is characterized

by the highest level of seismic activity; Transbaikalia with moderate seismic activity and with «transient» earthquakes emanating from the Baikal Rift Zone and Mongolia; and the southern Siberian Platform, which is practically aseismic with merely some «transient» earthquakes emanating from the Baikal Rift Zone (Berzhinski 2001). According to the review seismic zoning of the Russian Federation territory OSR-97 (Ulomov et al. 1999) the seismic intensity I which may occur in a given area within a 50-year time interval with the probability of exceedance equal to 10% (OSR-97A), 5% (OSR-97B) and 1% (OSR-97C) varies from I = V up to I = IX. Fig. 6 shows the fragment of OSR-97B map for the study area.

According to the studies of the Institute of the Earth Crust of the RAS Siberian Branch (Khromovskikh et al. 1996; Radziminovich 2003) there are few zones, which can be a possible source of a hazardous earthquake for the Irkutsk City. Their names and characteristics are given in Table 1. The value of the hypocenter depth h is estimated to be the same for all zones and equal to 15-20 km.

For the scenario earthquake, an earthquake with the epicenter located at $\varphi = 51.7^\circ$ and $\lambda = 103.6^\circ$ in the East Sayan source area extending along the Main Sayan Fault was chosen. The maximum magnitude M_{max} for this zone is estimated at 8.0, with hypocentral depth $h = 20$ km. The impact of the scenario earthquake was calculated using the AIUS RSChS software (Extremum System) (Larionov et al. 2000; Larionov et al. 2003a; 2003b; Sushchev et al. 2010;

Larionov et al. 2017).

State of damage d calculations were based on regional calibration parameters that determine earthquake vulnerability functions in accordance with the regional seismic intensity scale (Berzhinski 2001) (Table 2) and generalized vulnerability function parameters used in the AIUS RSChS for «default» calculations in any region worldwide in case no regional functions are available (Table 3). The generalized parameters were derived by processing an empirical data set on earthquake impact observations for earthquakes of intensity I greater than VI MMSK-86 grades that have occurred since the 1960s in Russia, Moldavia, Georgia, Armenia, Turkmenia, Uzbekistan, and other countries.

The impact of the scenario earthquake for the test region was found by calculating the refined parameters of N.V. Shebalin's macroseismic field model $I = 1.5M - 3.44 \lg(r) + 3.13$ that was previously reported in (Frolova et al. 2019). The anisotropy of the macroseismic field was incorporated by using a compression ratio k equal to 1.5 and by arranging the greater axis of the isoseismal ellipse along the fault field.

The rms deviation of the intensity $\sigma_I = 0.5$ was used for buildings of all vulnerability classes and for all observed degrees of damage in order to obtain the interval estimates (Aleksandrov et al. 2019).

The results of the scenario earthquake impact calculations are presented as tables, which show estimated proportion of buildings in the settlement that have received a certain state of damage d, as well as the average damage state for the town d_{aver} . The average state of damage d_{aver} is also shown on thematic maps in Figs. 7 and 8.

In these figures, the size of symbols indicates the number of inhabitants on the settlement and the color of a symbol shows the average state of damage inflicted on the structures.

Figure 9 shows the percentage of cities, in which buildings have suffered different average degrees of damage when using two considered vulnerability functions.

Tables 4 and 5 show the proportion of buildings in the larger settlements that have received a certain state of damage d and average states of damage d_{aver} for the buildings in a settlement as a whole.

Comparison of Figs. 7 and 8 shows a systematic overestimation of the damage, calculated based on parameters of the generalized vulnerability functions (Table 3) compared to the simulation results, obtained using parameters of the regional vulnerability functions (Table 2). Figure 8 shows, that most of the settlements are characterized by the average state of damage between $d_{aver} = 3$ and $d_{aver} = 5$. When the regional vulnerability functions are used, the number of settlements that have suffered a high level of damage is considerably reduced. The number of settlements with average damage state $d_{aver} = 5$ is reduced by a factor of three and that with $d_{aver} = 4$ almost by a

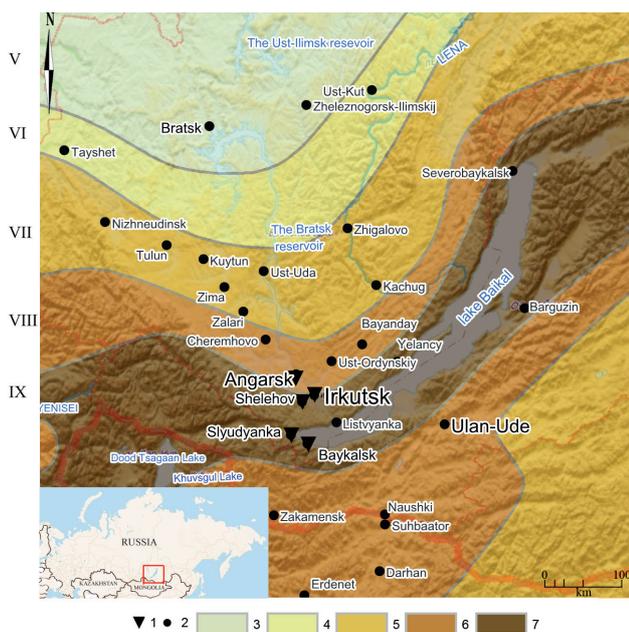


Fig. 6. The boundary of the test region modified after (Berzhinski, 2001)

1. settlements with representative buildings for vulnerability study;
2. industrial centers and transport hubs;
3. OSR-B zone with I=V;
4. OSR-B zone with I=VI;
5. OSR-B zone with I=VII;
6. OSR-B zone with I=VIII;
7. OSR-B zone with I=IX

Table 1. The most hazardous possible earthquake source zones for Irkutsk City

Possible source zone names	Minimum distance to Irkutsk City, km	M_{max}	Calculated intensity I in Irkutsk City, MMSK-86 grades
East Sayan	70	8.0	8.6
Tunkinskaya	140	7.5	6.6
Primorskaya sublatitudinal	70	7.5	8.8
Primorskaya southern	75	7.0	7.9
Marine	150	7.5	8.1

Table 2. The regional parameters of vulnerability functions in accordance with the regional scale of (Berzhinski 2001; Sherman et al. 2003)

Building types according to the regional scale	Buildings damage state d				
	Light d=1	Moderate d=2	Heavy d=3	Partially destroyed d=4	Completely collapsed d=5
	Mathematical expectation of the intensity I which results in a certain damage state of a building				
A, E5	6.2	7.0	7.8	8.6	9.4
B, E6	6.4	7.4	8.4	9.4	10.4
C, E7	6.7	8.0	9.1	10.1	11.0
E8	7.3	8.7	9.8	10.7	11.3
E9	8.3	9.5	10.4	11.2	11.5

Table 3. The default parameters of generalized vulnerability functions used in the Extremum System (Larionov et al. 2003a)

Building types according to MMSK-86 scale	Buildings damage state d				
	Light d=1	Moderate d=2	Heavy d=3	Partially destroyed d=4	Completely collapsed d=5
	Mathematical expectation of the intensity I which results in a certain damage state of a building				
A1, A2	6.0	6.5	7.0	7.5	8.0
B1, B2	6.5	7.0	7.5	8.0	8.5
C1, C2	7.0	7.5	8.0	8.5	9.0
E7	7.5	8.0	8.5	9.0	9.5
E8	8.0	8.5	9.0	9.5	10.0
E9	8.5	9.0	9.5	10.0	10.5

The rms deviation of the intensity $\sigma_I = 0.5$ for all types of buildings.

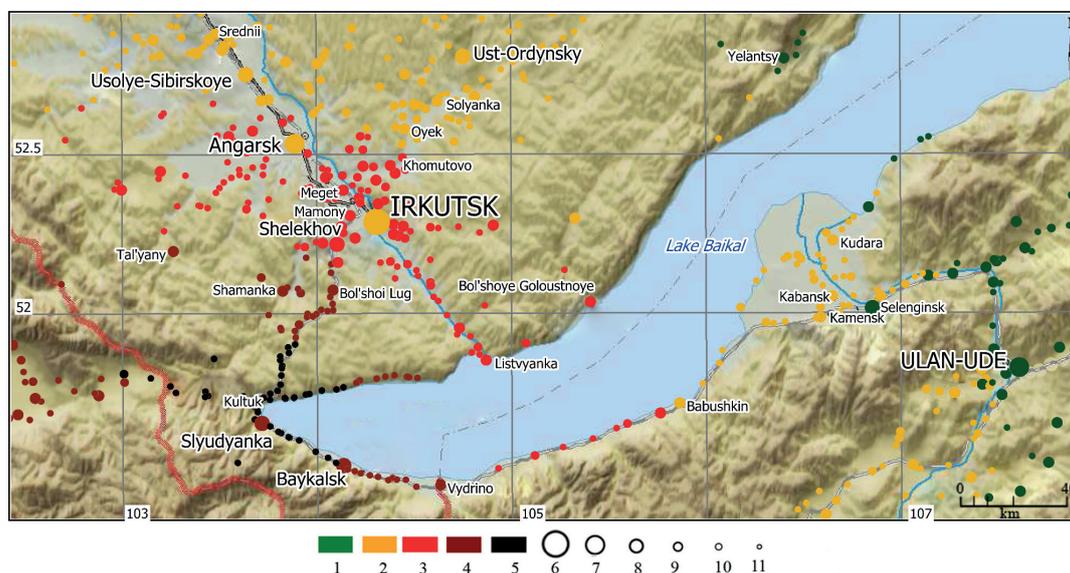


Fig. 7. The theoretical impact of the scenario earthquake in the East Sayan seismic source zone obtained using calibrated regional parameters of the vulnerability functions (shown in Table 2)

Average state of damage d_{aver} : 1-1; 2- 2; 3- 3; 4- 4; 5- 5; Number of inhabitants: 6 – 500,000 and more; 7 - 100,000 up to 500,000; 8 – 10,000 up to 100,000; 9 – 5,000 up to 10,000; 10 – 500 up to 5,000; 11 - less than 500.

factor of two (Fig. 9). Towns with the average state of damage $d_{aver} = 1$ and $d_{aver} = 2$ can also be found on the map, presented in Fig. 7. Overall, the difference between the average state of damage calculated using different approaches varies between 0.5 and 1.5 (Fig. 10).

According to Table 5, when the city of Irkutsk experiences the impact of the scenario earthquake, the fraction of buildings that can receive heavy damage or completely collapse is

approximately 30%. Meanwhile, according to Table 4, there will be no cases of heavy damage or complete building collapse and over 50% of all buildings in the city can be moderately damaged (d_2).

Thus, the use of calibrated parameters of vulnerability functions in accordance with the regional seismic scale for the Baikal Region and Transbaikalia provides evidence of the importance of incorporating region-specific structural features.

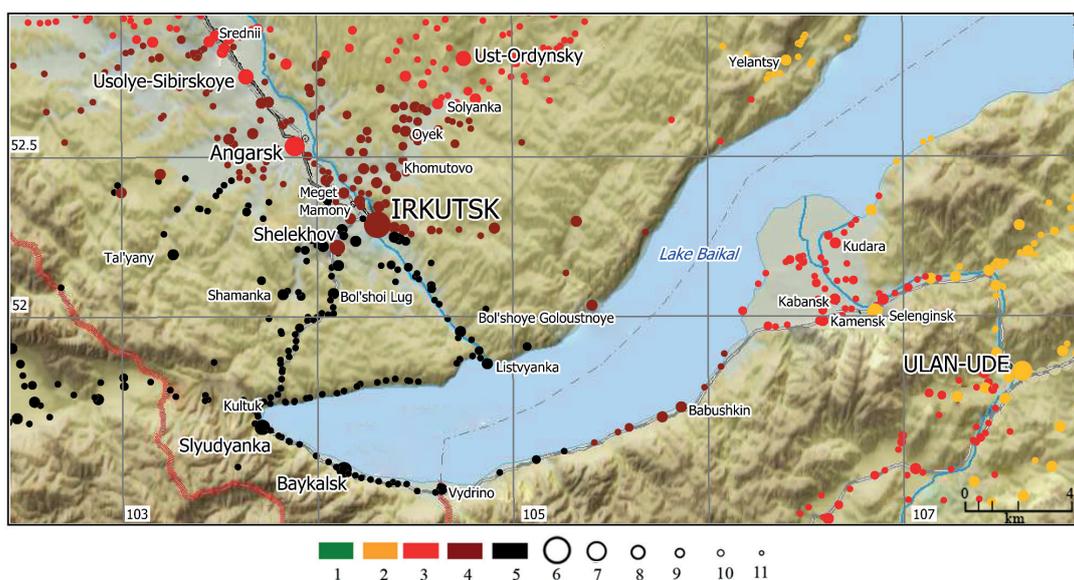


Fig. 8. The theoretical impact of the scenario earthquake obtained by using parameters of the generalized vulnerability functions (shown in Table 3)

Average state of damage d_{aver} : 1-1; 2- 2; 3- 3; 4- 4; 5- 5; Number of inhabitants: 6 – 500,000 and more; 7 - 100,000 up to 500,000; 8 – 10,000 up to 100,000; 9 – 5,000 up to 10,000; 10 – 500 up to 5,000; 11 - less than 500.

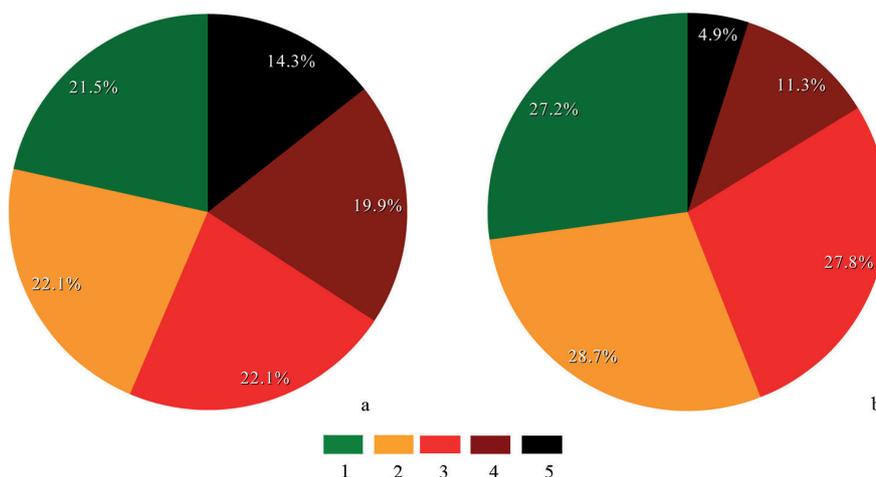


Fig. 9. Distribution of settlements with different damage grades; a - when using parameters of the generalized vulnerability functions; b - when using parameters of the regional vulnerability functions

Table 4. The estimated proportion of buildings that have received a certain state of damage d due to the scenario earthquake obtained using parameters in the regional vulnerability functions presented in Table 2

Settlement	Fraction of buildings with a certain state of damage					d_{aver}
	d_1	d_2	d_3	d_4	d_5	
Irkutsk	0.133	0.521	0.287	0.055	0.003	2.27
Shelekhov	0.064	0.465	0.365	0.097	0.008	2.518
Angarsk	0.254	0.525	0.195	0.023	0	1.979
Uso'le -Sibirskoe	0.405	0.464	0.111	0.008	0	1.697
Bajkalsk	0	0.069	0.422	0.355	0.149	3.571
Slyudyanka	0	0	0.083	0.412	0.504	4.418
Utulik	0	0.007	0.067	0.248	0.678	4.596
Kultuk	0.039	0.333	0.513	0.112	0	2.692

Table 5. The estimated proportion of buildings that have received a certain state of damage d due to the scenario earthquake obtained using parameters in the generalized vulnerability functions presented in Table 3

Settlement	Fraction of buildings with a certain state of damage					d_{aver}
	d_1	d_2	d_3	d_4	d_5	
Irkutsk	0.03	0.134	0.248	0.285	0.298	3.673
Shelekhov	0.012	0.078	0.191	0.284	0.435	4.051
Angarsk	0.076	0.211	0.286	0.248	0.17	3.196
Usol'ye -Sibirskoe	0.149	0.274	0.28	0.181	0.079	2.656
Bajkalsk	0	0.001	0.012	0.064	0.922	4.905
Slyudyanka	0	0	0	0.001	0.998	4.997
Utulik	0	0	0.003	0.013	0.983	4.977
Kultuk	0.009	0.037	0.141	0.326	0.485	4.232

DISCUSSION OF THE RESULTS

The present paper focuses on the AIUS RSChS database, which contains descriptions of the earthquake events; the database allows for subsequent improvements to the entire Extremum System by incorporation of the collected and systematized data from assessments of the situation in a disaster zone. The results of field surveys covering both the observed impact and a description of the location, time, seismic intensity, and type of the damaging excitation at various sites are recorded in the database. During calibration, the expected states of damage obtained by modeling are compared with the results of field surveys in the disaster zone. The goal of this comparison is to minimize the discrepancies, which is necessary for calibration of the mathematical models for vulnerability of buildings. A result that differs from the observed value by no more than 30% is generally considered to be acceptable.

When dealing with seismic events that involve damage and destruction of buildings, the database enables successive calibration of the vulnerability models. The first step includes classification of the buildings, defining the boundary of the region where the construction code, structural solutions, and construction materials are similar. The next step consists of adjusting the parameters of the vulnerability functions in order to minimize the discrepancies between the modeling results and observations. In the considered case, we adjusted the mean intensity I and the rms deviation of the intensity σ

so that the buildings arranged over different building types or vulnerability classes receive a certain average damage state. The procedure assumes that intensity I is a continuous random variable and that considered building belongs to a single building type or vulnerability class. This procedure is commonly used when developing regional seismic intensity scales. One such seismic intensity scale for the Siberian region of Russia is presented in the current paper. The use of this scale to simulate the impact of a scenario earthquake occurring in the earthquake generation zone of the greatest hazard for Irkutsk City has enhanced the accuracy of the simulation results, including the degrees of damage to buildings.

The example (Table 2, Table 3, Figure 7, and Figure 8) compares the results of modeling the impact of a seismic event with all equal parameters, except for the parameters of the vulnerability functions. The example shows that the use of generalized parameters considerably increases the errors in assessing the consequences of an earthquake compared with the case when the regional parameters were used. From this example it can be seen that the use of generalized data on vulnerability for assessing earthquake impact was a matter of necessity for users of the Extremum System. It can also be concluded from the example that all seismic events should be recorded with subsequent incorporation of the survey results in the database, thus enabling refinement of the regional scales and calibration of the system in order to enhance the accuracy of near real-time damage and loss estimates.

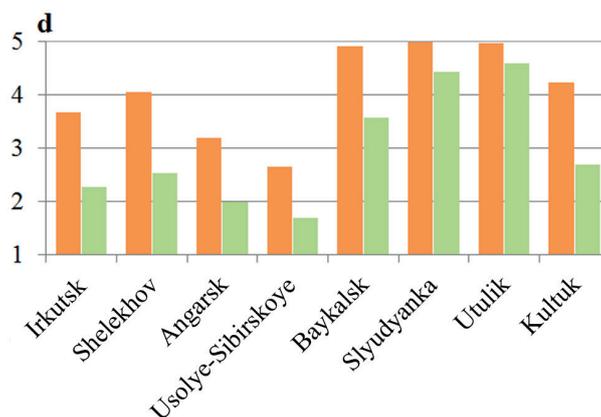


Fig. 10. The distribution of the average state of damage in a town as a result of the scenario earthquake obtained using regional and generalized vulnerability functions for the structures in the region: orange – values of d_{aver} from Table 5; green – values of d_{aver} from Table 4.

CONCLUSIONS

1. The studies have shown that the use of a database with descriptions of seismic events for calibrating a seismic vulnerability model yields a noticeable effect that provides acceptable accuracy for the near real-time simulation of a possible earthquake scenario.
2. Calibration can have positive effect on the results if the following conditions are met:
 - A special AIUS RSChS database receives detailed information on the level of damage to buildings due to each seismic event. The structure of a record has special sections for storing formalized data on the location of the study object (coordinates and address), a description of its structural design and construction materials, an assessment of earthquake resistance carried out when the object was subjected to inventory, damage suffered due to the seismic excitation of a certain intensity.
 - interconnection is established between the records with descriptions of events and their impacts.
 - the database used for calibration contains information on the boundary of the region where the same calibration parameters are used. For all seismic events that fall in a selected region, the same set of vulnerability functions will be used; the functions are characterized by the mean and rms deviation of the intensity;
 - there is an indication of the seismic intensity scale, which is used to classify the buildings within the region.
3. The goal of the calibration process is to minimize the discrepancies between the degrees of damage that were obtained by modeling and those reported after the field

survey. The calibration is performed by adjusting the mean and rms deviation that characterize each vulnerability function. This can only be done with a fixed seismic intensity scale that provides a detailed description of the vulnerability classes.

4. The structure of the AIUS RSChS data depository has been adjusted in the optimal way to provide the storage of the calibration data. The data are collected by the survey specialists from the sites and are revised in subsequent reports of engineering seismologists and structural designers, as well as in scientific publications that contain analyses of the observations.
5. After revision of the records or input of additional data, a second calibration is carried out to improve (by self-learning processes) those blocks in the System which are responsible for the simulation of possible earthquake scenarios.
6. The example given in the paper illustrates the influence of vulnerability functions on the damage simulation results and demonstrates the importance of taking the regional characteristics into account. Modeling of the impact of the scenario earthquake with the epicenter in the East Sayany source zone has shown that the use of region-specific parameters in the vulnerability functions yields more reliable estimates of potential damage and losses due to a large earthquake. For Irkutsk City, the estimated number of heavily damaged and completely collapsed buildings obtained using different sets of parameters for vulnerability functions differs by 30%, which can significantly affect the plans for rescue and recovery operations. ■

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