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Update of Normative Seismic Zoning in the Framework of the Integrated Information System for the Seismic Safety of Russia

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Abstract—The article deals with updating databases and the general seismic zoning maps of the Russian territory (GSZ-97). Development of new maps (GSZ-2012) is considered. Recommendations on updating the building codes are made. The article reports on the development of the Integrated Information System "Seismic Safety of Russia" that involves operation of the specialized interactive maps of seismic hazard forecast.

Keywords: seismic zoning, seismic hazard, seismic effect, macroseismic regime, building codes

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INTRODUCTION

The first step to diminish devastating effects from strong earthquakes is reliable zoning of seismic hazard and respective seismic engineering. The important factors, on which the number of deaths and damage done depend, are the knowledge of the local population and authorities on earthquake hazards and the ability to survive a disaster. Solution of these and many other problems related to diminishing seismic hazards in the territory of Russia is provided by the Federal Special-Purpose Program (FSPP) entitled "Enhancement of Seismic Sustainability for Dwellings, Main Objects, and Facilities in the Regions of Russia Prone to Seismic Hazards (2009–2014)" and affirmed on April 23, 2009. In accord with this FSPP, research works were revitalized concerning a series of problems, including those in updating of such regulating documents as SNiP II-7-81* (1995; 2010 update) and maps of general seismic zoning (GSZ-97) for the territory of Russia. In order to elaborate suggestions and recommendations for solving the problems of provisional seismic safety of buildings and facilities, the Expert Commission for Seismic Engineering had been organized under the jurisdiction of the Minregion (Ministry of Regional Development of the Russian Federation) on August 15, 2009; the author is one of the members of this Commission.

Among the most important tasks set by the Minregion was the creation of the permanent Integrated Information System (IIS) "Seismic Safety of Russia," which began its operation in test mode in late 2011. The main purpose of the IIS is to provide authorities, interested organizations, and common people with the most complete, up-to-date, and reliable information on the problems of seismic safety implementation in the territory of Russia. The leading development organization was the Geological Research Institute for Construction (AO PNIIIS); the main contractor in the part of seismology was the Schmidt Institute of Physics of the Earth, Russian Academy of Sciences (IPE RAS), which continued its work on updating seismic zoning (Ulomov, 2008a, 2008b, 2009b). In the same period, the works on updating the regulatory framework (SNiP II-7-81*) were revitalized (Aizenberg, 2010).

At the initiative of the author, together with updating the GSZ-97, development of the new generation of GSZ-2012 maps began in the framework of IIS (however, this was not among the tasks set by Minregion). At the first stage of work, in 2010–2011, test maps for two versions of models depicted the earthquake source zones (ESZ) in the territory of Russia and adjacent regions. SNiP II-7-81* and the principles of probabilistic assessment of seismic hazard (PASH) and perfection of general and detailed seismic zoning (GSZ and DSZ) and microzoning (SMZ) were further developed. The projects of technical rules for implementing the works on GSZ (Code of Rules, statuses of GSZ, DSZ and SMZ) (Ulomov and Nikitin, 2010).

For the purpose of coordination of the whole complex of research in the framework of the FSPP, the dedicated groups were organized for updating the GSZ (headed by V.I. Ulomov, IPE RAS) and SNiP II-7-81* (headed by N.I. Frolov, NP SRO NOSTROI). These groups included leading specialists from different academic institutes and specialized institutions of Russia.

The studies of seismic zoning were carried out simultaneously in two main fields:

1) creation of the updated set of GSZ-97* maps (enhanced and supplemented version of the existing GSZ maps for the territory of Russia);

2) development of a new GSZ concept and creation of model maps showing earthquake source zones in the territory of Russia for the GSZ-2012.

The following are the main results of seismological studies obtained in 2010–2011 by the group consisting of large number of specialists with participation and under the leadership of the author.

The present paper is published with respect to the joint proposal of the Science Council of the Problem of Seismology, Russian Academy of Sciences (chairman is a Corresponding Member of the RAS, G.A. Sobolev) and the Council on the Problems of the Earth's Seismicity and Natural and Natural–Technogenic Catastrophes in the IPE RAS (chairman is Dr. Phys.-Math. Sci., A.D. Zavyalov) made on February 17, 2011: "To ask the member of the Council of the Problem of Seismology of the RAS, Prof. V.I. Ulomov, to deliver the report about the planning and carrying out of works on the improvement of the general seismic zoning map of Russia, and to report the methodical points of the prepared changes in a scientific journal" (minutes of meeting no. 1/2011).

INITIAL DATA AND STUDY METHODS

Basic Definitions

Seismic hazard (SH) means the maximal seismic effects which are expected in a given area and may be exceeded at a set probability during a set time interval. Seismic effects are measured in points of macroseismic scale, as well as in peak accelerations and other quantitative parameters of ground motion, used in seismic engineering. The seismic hazard level and degree of vulnerability for artificial and natural objects cause the value of seismic risk estimated on the basis of expected socio-economic damage.

General seismic zoning (GSZ) means mapping of a seismic hazard over the whole territory of a country; this mapping is based on studies of seismicity and the seismic regime of regional, interregional, and large global seismogenerating structures (SGS). The GSZ maps are the components of a normative and legislative framework that provide well-sounded land use, socio-economic development, environmental protection, seismic engineering, and population safety when strong earthquakes occur at the national, regional, and subregional levels.

Seismicity of Russia

Hereinafter, the term "seismicity" is used in its specific, geological-geophysical sense instead of the meaning implied by Russian designers and builders with respect to the results of seismic zoning. Beyond Russia and the former Soviet Union, these results of seismic zoning are called "seismic hazard" or "shakeability", after the suggestion by Yu.V. Riznichenko in the mid-1960s (Riznichenko, 1965, 1966). To prevent ambiguity and misunderstanding, it seems reasonable to define the results of seismic zoning as "macroseismicity," but not seismicity (Ulomov, 2009b).

In terms of seismology, seismicity is the spatiotemporal and energy distribution of earthquake focuses, characterized by magnitude, depth and size of source, seismic regime, and other geophysical parameters. In other words, seismicity and seismic regime mean what occurs in the earth's interior, while macroseismicity and macroseismic regime imply manifestations of the seismic effects on the earth's surface. These manifestations are estimated in points of macroseismic scale, accelerations of ground motions, and other parameters related to the seismic effects.

Compared to other countries of the world, located in seismoactive zones, the territory of Russian Federation is generally characterized by moderate seismicity (Fig. 1) (Ulomov, 2004, 2007). The only exclusions are the regions of Northern Caucasus, Southern Siberia, and the Russian Far East, where intensities of seismic shaking reach 8–9 and 9–10 on the MSK-64. A certain hazard can be expected in the zones of 6–7 on the MSK-64, located within the densely populated regions in the European part of Russia.

In the global framework, the territory of Russia belongs to Northern Eurasia, whose seismicity is caused by intensive geodynamical interaction of several large lithospheric plates: Eurasian, African, Arabian, Indo-Australian, Chinese, Pacific, North American, and Okhotsk. The most mobile and hence active are the plate boundaries where large seismogenerating orogenic belts are formed: Alpine-Himalayan in the southwest, Transasian in the south, Chersky in the northeast, and Pacific in the east of Northern Eurasia.

Every belt is inhomogeneous in structure, strength properties, and seismogeodynamics, and consists of uniquely structured seismoactive regions that can be pictured as ordered and genetically related geostructures (Ulomov, 1993, 1997).

The characteristic feature of all seismoactive regions is nearly the same length (about 3000 km), which is caused by the sizes of ancient and modern subduction zones (located in the periphery of oceans) and their orogenic relics within the continents. The predominant part of all earthquakes is concentrated in the uppermost crust at the depths of 15–20 km. The deepest (down to 650 km) focuses were reported for the Kuril-Kamchatka subduction zone. The earthquakes having an intermediate depth of focuses (70–300 km) occur in East Carpathians (Romania, Vrancea zone, down to 150 km depth), in Central Asia (Afghanistan, Hindu Kush zone, up to 300 km depth), and beneath the Greater Caucasus and Central Basin of the Caspian Sea (down to 100 km and deeper) (Ulomov et al., 2007). The strongest events occurring in these regions are felt in the territory of Russia.

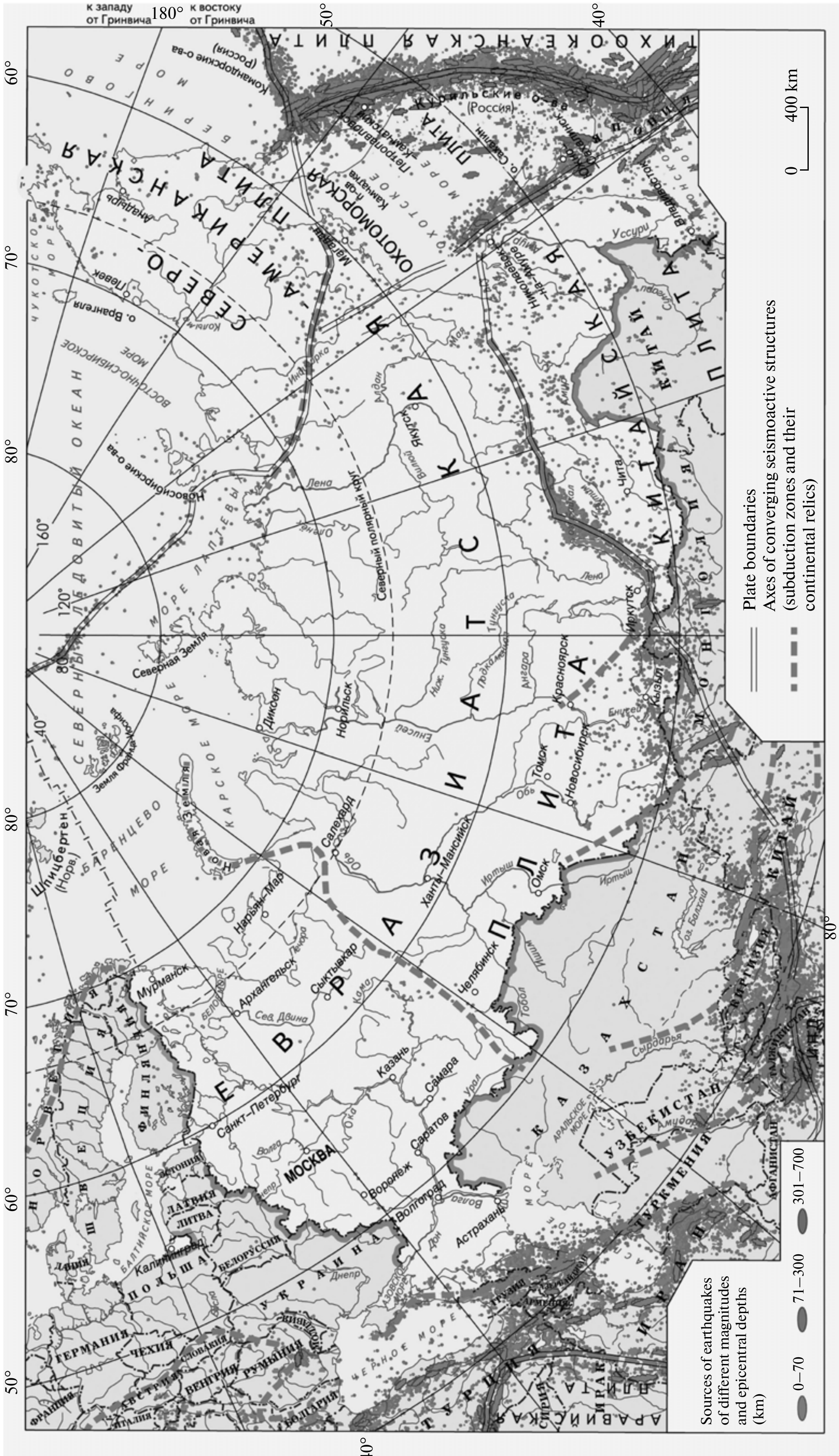


Fig. 1. Seismicity of the territory of Russia and adjacent regions. M 1 : 40 000 000. Special content is developed by V.I. Ulomov.

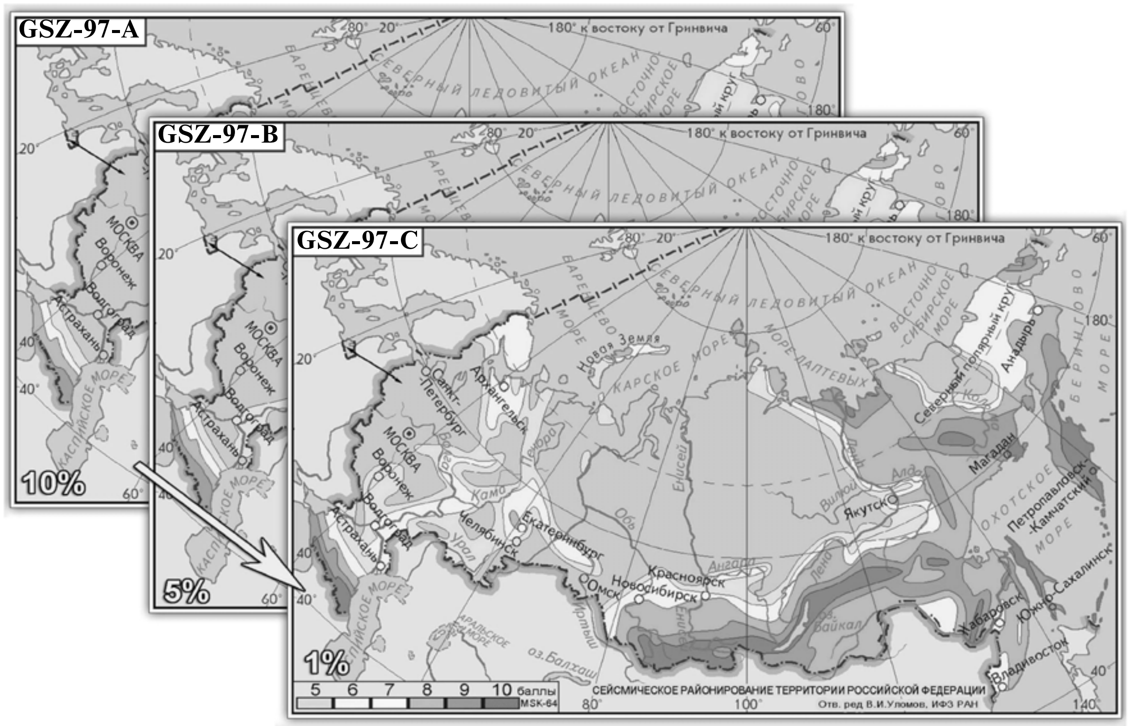


Fig. 2. GSZ-97 standard maps showing general seismic zoning of the territory of the Russian Federation. Edited by V.I. Ulomov.

Every region has a specific periodicity of earthquake occurrence (that determines the seismic regime) and migration of seismic activation along the seismoactive faults. Sizes (lengths) of every source cause the magnitude value of an earthquake. The rupture length in a source of an event with $M_s = 7.0$ and higher reach tens and hundreds of kilometers.

Zoning of Seismic Hazard

In 1991–1997, thanks to the development of consistent methodology and advances in probabilistic approaches in seismic zoning of Russia, the paradigm of seismic hazard estimation changed. The unified database of initial seismological and other geological-geophysical data has been organized for the vast area of Russia and adjacent seismoactive regions for the first time; additionally, the fundamentally new lineament-domain-focal model (LDF-model) for ESZs with adequate seismogeodynamical parametrization has been developed (Ulomov, 1998). Instead of traditionally one deterministic map, for the first time in the world's seismological practice, the set of probabilistic maps GSZ -97 (Fig. 2) began to be used; this set of maps was the first step of the fundamentally new seismic zoning, which took into consideration dynamics and the time factor (Ulomov and Shumilina, 1999a, 1999b, 2000; *Seismicheskoe*..., 2000).

GSZ-97 maps for the territory of the Russian Federation were officially adopted on March 23, 1998 by the vice-President of the RAS, Academician N.P. Laverov, received a status of normative regulations, and in 2000 were included into the modified version of SNiP II-7-81*. The new methodology and GSZ-97 set of maps were widely discussed at different scientific and governmental levels and in 2002 were awarded the State Prize of the Russian Federation (in the field of Science and Technics). These maps have proved their validity through all the consequent seismic events that have occurred in the country for the 15 years that followed. In addition to numerous weak and moderate events, earthquakes of 8–9 and even more on the MSK-64 have occurred in this period (including those in Sakhalin, Altai Mountain, Koryakia, Kuril Islands). Remarkably, their seismic effects have not violated the probabilistic estimates given by the GSZ-97 maps. Nevertheless, analogous to the previous editions of the seismic hazard zoning maps that were updated every 10 years on average (since 1937), the GSZ-97 maps needed to be updated as well due to the new collected data on seismicity of the studied territory, and with respect to the appearing technical rules and new ideas.

Simulation of Earthquake Sources

The methodology of the construction of GSZ-97 maps is based on the regional approach in creating two mutually dependent seismogeological models, namely, the model of source zones (MSZ) and model of seismic effect (MSE) (Fig. 3). The concept of the

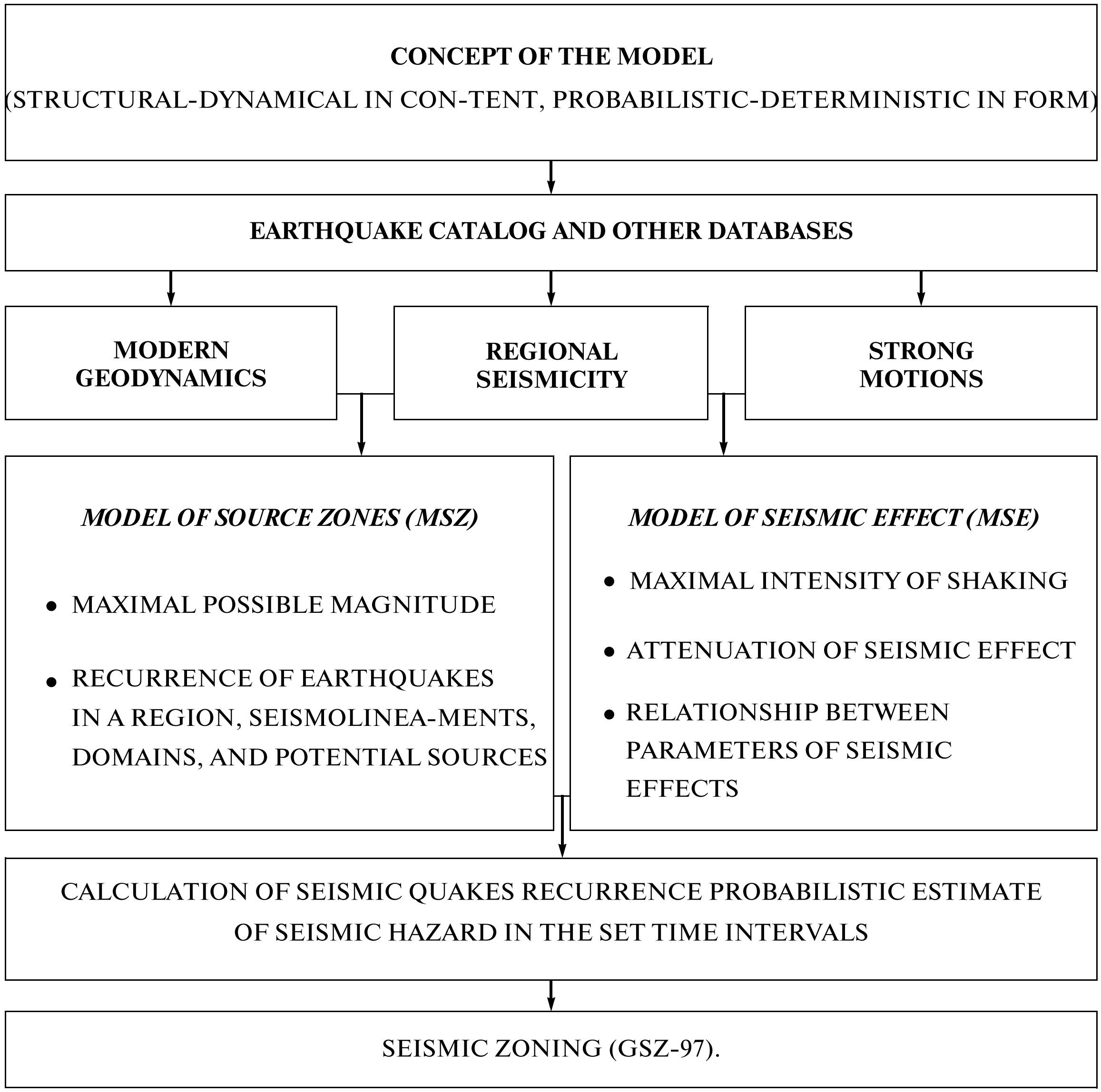


Fig. 3. Methodology of the GSZ-97 for identifying the ESZ and seismic zoning.

GSZ-97 reflects the structural-dynamical unity of the natural medium and probabilistic character of seismic processes within it. As is shown in Fig. 3, MSZs and MSEs are formed on the basis of three blocks of the initial database: modern geodynamics, regional seismicity, and strong ground motions. With the help of these initial data, the recurrence of seismic events is calculated and probabilistic maps of seismic zoning are compiled (Gusev and Shumilina, 1995; Ulomov and Shumilina, 1999a, 1999b).

The model of ESZs is based on the LDF model (Fig. 4), which is properly parametrized and then used in simulation of real seismicity. In accord with the adopted concept, the LDF-model considers four scale levels of earthquake sources: (1) a large region with its integrated characteristics of the seismic regime including three main structural elements described below. (2) Seismolineaments (SL), which are, in general form, axes of three-dimensional seismoactive faults or shear structures; SLs reflect structurized seismicity and serve as the main framework for the LDF-model. (3) Seismodomains (SD) that cover quasihomogeneous (in a geodynamical sense) volumes of the geological medium and characterized by scattered (“diffuse”) seismicity. (4) Potential earthquake sources (PES) indicating the most dangerous sites (focuses) in seismogenerating structures (situation and the maximal hazard of virtual sources can be revealed by deaggregation analysis of seismic hazard).

Lineaments, domains, and potential sources, as well as earthquakes proper, are classified in terms of maximal magnitude value (M_{max}) with a step of 0.5 and in the interval of ±0.2 M (hereinafter, M corresponds to M_s determined from surface seismic waves). The

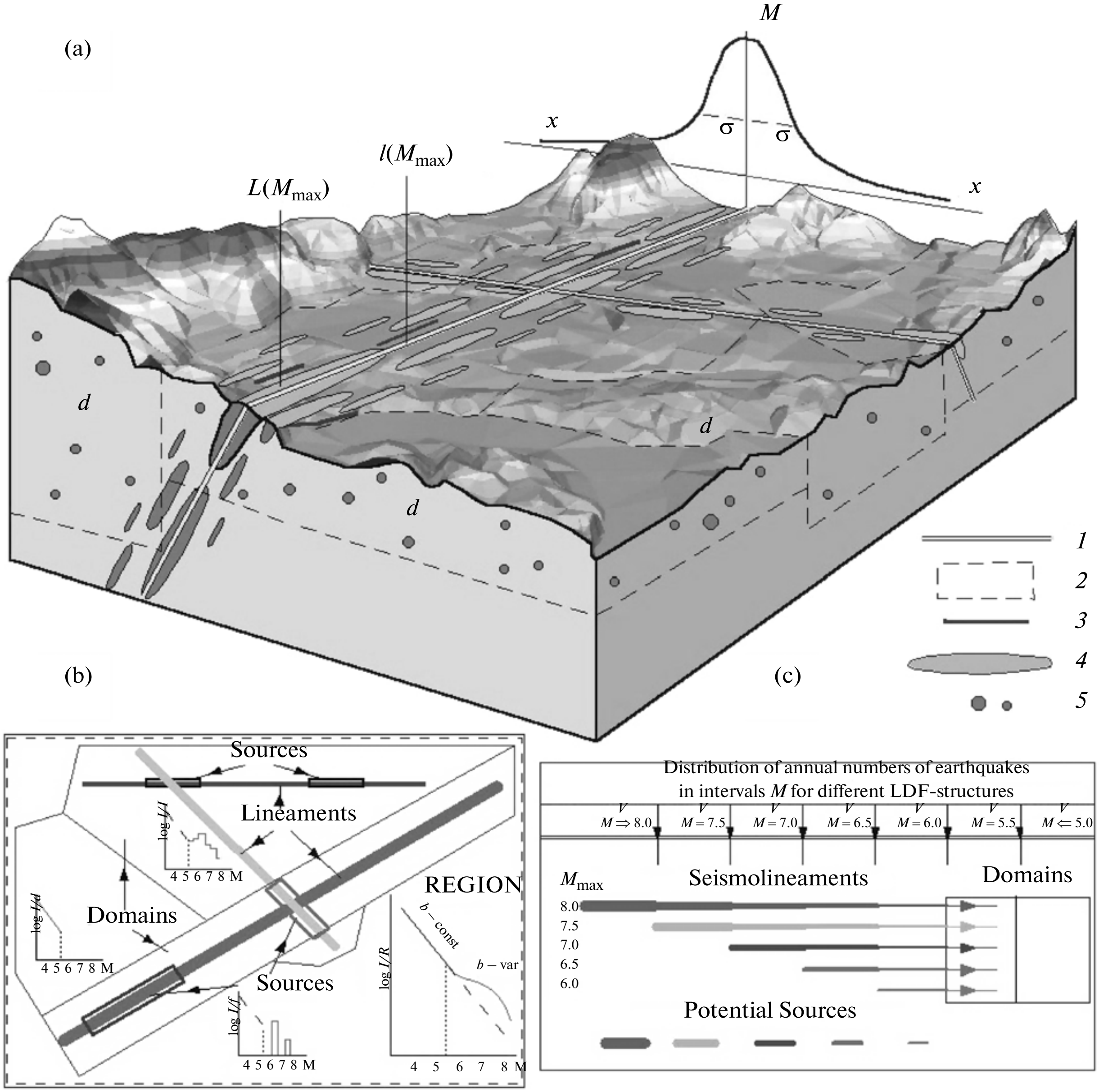


Fig. 4. The 3D lineament-domain-focal model of ESZ (a); the main structural elements of the region (lineaments, domains, potential sources) and their inherent recurrence graphs (b); distribution of average annual seismic events (V) of different magnitudes corresponding to M_{max} along lineaments, within domains, and in potential sources (c). *1*, axes of seismolineaments $l(M_{max})$; *2*, arbitrary boundaries of seismic domains; *3*, active fault lines; and *4*, sources of large earthquakes $L(M_{max})$ with $M_{max} \geq 7.0 \pm 0.2$; *5*, earthquake sources of earthquakes with $M_{max} \leq 6.5 \pm 0.2$; D means the distance from lineament axis; M, magnitude; d, domains; and σ, standard deviation.

minimal value of the earthquake's magnitude along the lineaments in the GSZ-97 is assumed at $M = 6.0$ (to say in more precise, $M = 5.8$, with ± 0.2 taken into account). This is caused by the fact that sources with smaller magnitude are identified insufficiently reliable at generalized zoning (that is GSZ by its nature); in the case of DSZ, a lower threshold of magnitudes for lineaments can be decreased.

Since the real sources are not located strictly along the SL axes and can occur at certain distances from SLs, simulation of virtual seismicity utilizes the functions of statistical distribution analogous to that shown in the background of Fig. 4. The lower the magnitude of an earthquake the larger the distance from the SL axis for such sources. This scatter is caused by the size of zones of dynamical influence made by lineament structures on the adjacent geological medium with its fractal structure.

The earthquake sources of $M = 5.5$ (to say more precisely, $M = 5.7$ and less) belong to domains. Their

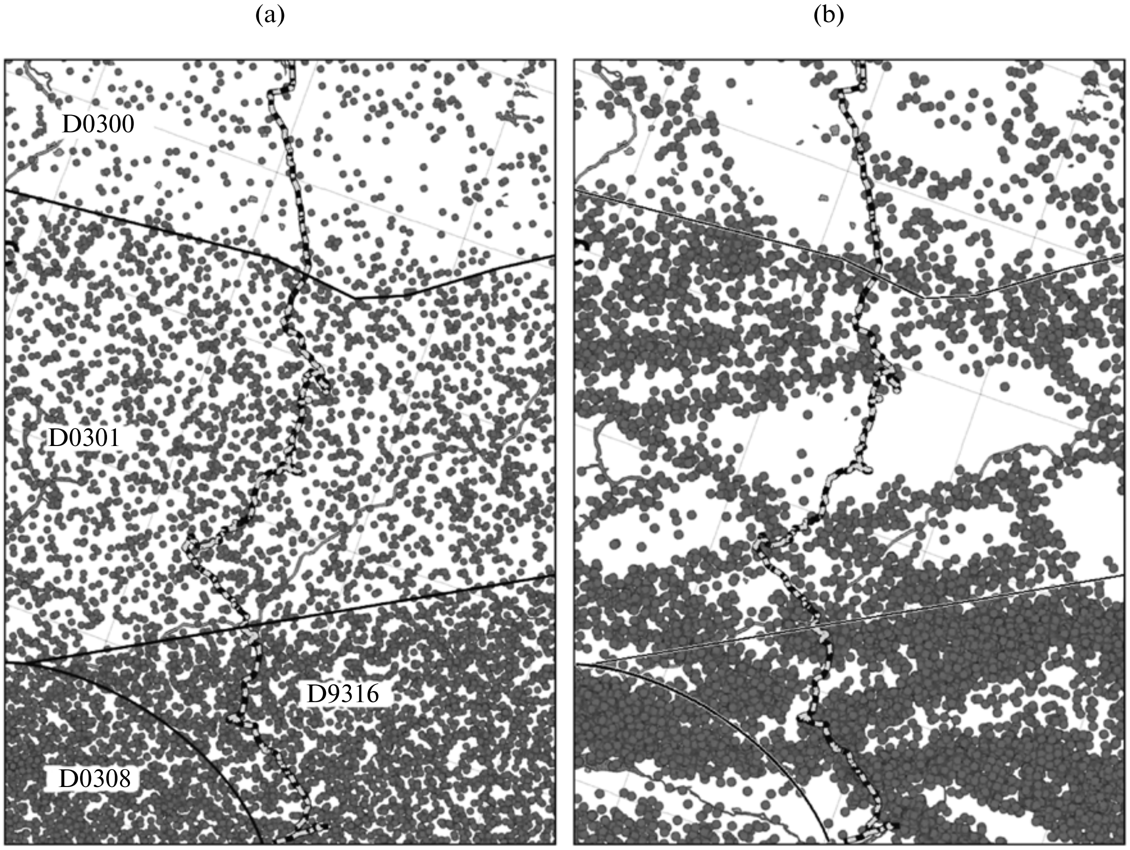


Fig. 5. Transformation of the scattered distribution of earthquake epicenters within domains D (a) into the structurized seismicity localized along lineaments of less orders (b). Average annual number of seismic events in the same areas remains the same.

upper threshold can also be decreased when detailing GSZ maps, while sources proper, which are "scattered" within domains, are grouped into clusters with respect to lineaments of fewer orders, as it is shown in Fig. 5 (Ulomov, 2009a). In these constructions, model values of probable deviations of earthquake focuses from axes of respective lineaments for the GSZ (Table 1), supplemented with values for lower magnitudes, have been used.

Determination of seismic regime parameters for the main structural elements of the LDF-model is the most difficult and the most important part of studies

Table 1. Deviation σ_M for source displacement relative to lineaments' axes

M_{max}	σ_M value (km) for lineaments possessing $M = M_{max} - n$					
	$n = 0.0$	$n = 0.5$	$n = 1.0$	$n = 1.5$	$n = 2.0$	$n = 2.5$
8.5	12	17	25	35	51	73
8.0	10	15	21	30	43	62
7.5	9	12	18	25	35.5	50
7.0	7	10	15.2	21	30	42
6.5	6	8.4	12.9	18	24.5	
6.0	5	7	11	15		
5.5	4.2	5.8	9.3			
5.0	3.5	4.9				
4.5	3					

related to seismic zoning, because validity of all the subsequent constructions depends on this. The detailed description of the parameterization technique is given in the explanatory note to the GSZ-97 maps (Ulomov and Shumilina, 1999a) and in some other publications by the author. Additionally, Fig. 4b illustrates distribution of earthquakes with different magnitudes, and Fig. 4c shows that of seismic event flows between the main structural elements of the whole region (lineaments, domains, and potential sources).

The basis of seismological parameterization is the regional approach caused by global ordering of seismoactive regions (Ulomov, 1993, 1997). The regional approach has significant advantages in comparison to other ones used for estimation of the maximal possible magnitude (M_{max}) and determination of the seismic regime of seismogenerating structures. At first, a region of about 3000 km in size has a physically substantiated nature and can be considered as a "seismogeocenosis" that includes all structural elements. Secondly, the large area of a region (compared to that of a particular fault) enables one to obtain a quite complete catalog of earthquakes with different magnitudes, and therefore, more reliable data on the seismic regime of a region on the one hand and on structural elements, between which the integrated flow of seismic events distributes with respect to their order (size and M_{max}), on the other hand.

Probabilistic Analysis of Seismic Hazard

Solution of almost all problems related to the prediction of a seismic hazard involves probabilistic and probability-determined characteristics that take into account both random and regular factors of seismogenesis, as well as various uncertainties in initial and output data, which can violate the validity of the deterministic approach to seismic zoning. At present, the most reliable zoning can be implemented only on the probabilistic basis. In other words, seismic hazards will always happen, but they should be reduced to a minimum and find convenient guidelines in building. This principle is what GSZ-97 maps and their updated versions GSZ-97* imply, so the degree of seismic hazard for objects of different categories of importance and service life can be assessed.

The methodology of PASH has been widely used in international seismological practice and has become the foundation of GSZ-97 maps; it is still used because there is no other, more efficient method.

In the GSZ-97 maps, the PASH results are presented in the form of model seismic intensity I with average recurrence of one time per T years. Probability P that this intensity will increase for t years (i.e., at least one stronger event will occur) is calculated by the formula

$$P = 1 - \exp(-t/T).$$

E.g., at $T = 500$ years and $t = 50$ years, $P \approx 10\%$ (to say more precisely, 9.52%); at $T = 1000$ years and $t = 50$ years, $P \approx 5\%$ (the precise value is 4.88), etc.

The GSZ-97 set include three maps that reflect probabilities of 10% (GSZ-97A), 5% (GSZ-97B) and 1% (GSZ-97C) that the model seismic intensity will be exceeded (or vice versa, will not be exceeded in 90, 95 and 99% of cases, respectively) for 50 years; this corresponds to the recurrence period of seismic effect manifestation on the earth's surface one time per 500, 1000 and 5000 (the precise values are 475, 975 and 4975) years on average. For very important buildings (nuclear power stations and other objects of nuclear industry), the map GSZ-97D has been created; it takes into consideration the seismic effect from very rare earthquakes that occur in the studied territory one time per $T = 10000$ years ($P = 0.5\%$).

DESIGNING OF THE UPDATED GSZ-97* MAPS

Principles of the GSZ-97 Update

Figure 6 shows the method for updating the maps of GSZ; in fact, this method follows the pattern on which the GSZ-97 maps were created (see Fig. 3).

It should be noted that terminology problems (related to distorted term seismicity) were addressed in this case as well. E.g., the term "update of initial seismicity", which was widely used in the wrong sense by building and surveying specialists, has now "recovered" its meaning and implies "update of seismicity model" (i.e., update of the ESZ model). As the term "seismic hazard" was introduced into the international seismological practice, the author proposed in 2004 to use the term "update of seismic hazard" (USH), while the term "update of initial seismicity" (UIS) began to be used in its direct sense.

Update of the general seismic zoning (UGSZ) means the studies of seismoactive territories, made in more details (1 : 500000 and smaller) than the GSZ-97 studies were made (initial scale 1 : 2500000), resulted in the USH on the basis of the updated model of initial seismicity (MIS model) and model of intensity decrease with distance (IDD model) from the source.

Note that the same normative recurrence periods T should be kept, at that, because they are incorporated into the GSZ-97 and updated GSZ-97* maps (see below).

Thus, updating of the initial seismicity model is aimed at both an update of seismicity proper and an update of the LDF-model of ESZs that causes prediction of the seismic regime. The UHS is used for seismic hazard assessment in both particular points (indicated as USH-1 instead of the MIS model) and limited areas (USH-2, analog of DSZ in the probabilistic sense).

Note that, independently of whether a particular site (USH-1) or vast territory (USH-2) is considered,

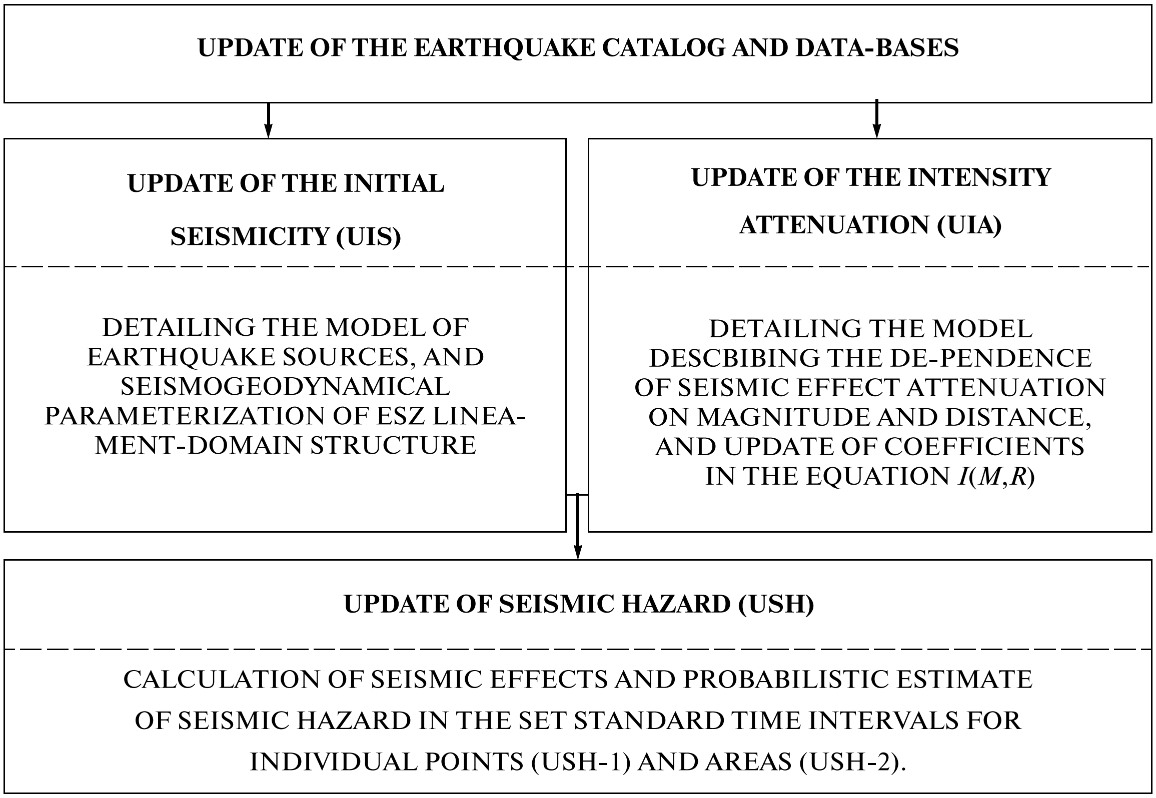


Fig. 6. Technique of updating the general seismic zoning (UGSZ).

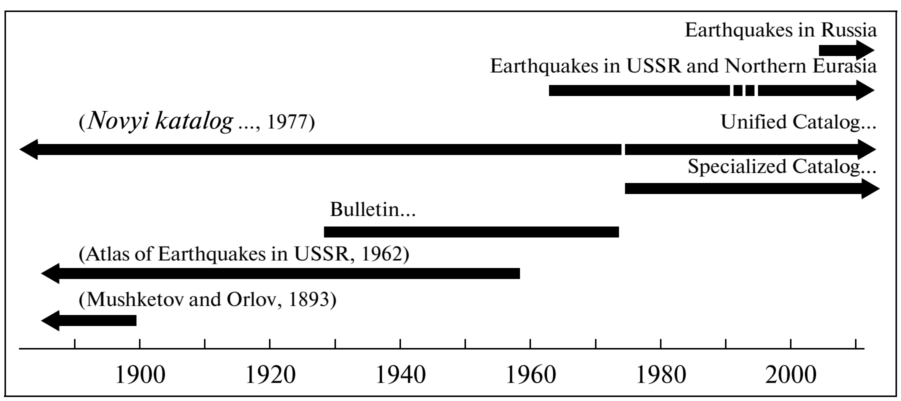


Fig. 7. The chronology and coverage of earthquake catalogs for the territory of Northern Eurasia. Annual catalogs: Bulletin of the Reference Seismic Network (since 1924; since 1962 was titled as Seismological Bulletin...), Earthquakes in USSR (since 1962), Earthquakes in Russia (since 2002), Earthquakes in Northern Eurasia; Unified Catalog of Earthquakes in Northern Eurasia (Ulomov, 1993); Specialized Catalog of Earthquakes in Northern Eurasia (Ulomov, 1996).

studies on UIS and IDD should involve quite large regions around the studied area, depending on the maximal magnitude of a possible event and effective attenuation of seismic intensity with distance.

As was noted above, probabilistic maps of GSZ and methodology of their making (LDF-model, normative recurrence periods, etc.) should be the basis for all works on DSZ (i.e., USH-1 and USH-2) and SMZ.

Update of the Earthquake Catalog

The earthquake catalogs remain the fundamental basis of all studies on GSZ of the territory of Russia. The works on updating the GSZ-97 maps and preparing the next generation of GSZ-2012 maps are also based on earthquake catalogs (Ulomov and Peretokin, 2010a, 2010b; Danilova and Medvedeva, 2011;

Nikonov and Shvarev, 2011; Nikonov, Medvedeva, and Shvarev, 2011).

Figure 7 shows the chronology of the publication of official earthquake catalogs; this timeline includes catalogs for the territories of the Russian Empire, Soviet Union, and modern Russian Federation. The first fundamental work among these publications was "The Catalog of Earthquakes in the Russian Empire" compiled by I.V. Mushketov and A.P. Orlov in 1893. By the time of the GSZ-97 maps publication, the most complete and well-known was the "New Catalog of Strong Earthquakes in the USSR from Ancient Times through 1975" edited by N.V. Kondorskaya and N.V. Shebalin (*Novyi katalog...*, 1977). An updated and modified version of this catalog, entitled "Unified Earthquake Catalog for Northern Eurasia" (UEC), was created in 1991–1995 and edited by N.V. Kondorskaya and V.I. Ulomov; this catalog was the basis of the general seismic zoning edition of 1997. Note that such a complete catalog was applied for seismic zoning for the first time, because the previous (and the most unsuccessful) zoning of 1978 was made before the "New Catalog..." was published.

Simultaneously, under the leadership of the author, the Specialized Earthquake Catalog (SEC) was being compiled in 1991–1995; it was purposed for seismological parameterization of the LDF-model and studying the migration of seismic activation (Ulomov, 1993; Danilova and Medvedeva, 2011). The main difference between the SEC and UEC is exclusion of aftershocks and other swarm events in order to obtain a "pure seismic regime" for further statistical study; other differences are the magnitude representation with a 0.5 unit step and averaging of magnitude values in the interval of ± 0.2 M_s. The information about source sizes and orientations for large earthquakes ($M_s = 7.0 \pm 0.2$ and more) was included into the SEC, and this information was introduced into practice by the author in the mid-1970s (Ulomov, 1974). In the sense of geometry, the SEC is represented in the GSZ-97 database in two representations: (a) points with arbitrary mapping of magnitudes and other geophysical parameters of earthquake sources, (b) polygons (ellipses and circles) that reflect natural sizes and orientation of earthquake sources in the best way.

In the period of 1992–1999, owing to participation of the IPE RAS in the Global Seismic Hazard Assessment Program (GSHAP) developed under the auspices of UNESCO, Russian catalogs were being adjusted to the European standards (Ulomov, 1999).

The UEC and SEC include the main parameters of all the known earthquakes with $M_s \geq 4.5$ since ancient times until present; since 1960, the catalogs are supplemented with events of $M_s \geq 3.3$ that are representative for almost the entirety of Northern Eurasia. At present, the UEC and SEC compiled at the IPE RAS are regularly supplemented with new data on occurring earthquakes thanks to the Geophysical Survey, RAS. Preparation of the historical, archeological, and paleoseismic information about the earthquakes that occurred in the pre-instrumental period is supervised by A.A. Nikonov (Nikonov and Medvedeva, 2011; Nikonov and Shvarev, 2011). The general supervision of the entire work on this project has been carried out by the author since 1991.

Specification of the UEC and SEC when making their updated version (GSZ-97*) was related mostly to the Eastern European part of Russia, e.g., the Tambov earthquake of December 30, 1954 ($M = 4.8$) was excluded from the catalog because of its technogenic origin (however, it was believed to be a tectonic one for a long time, and therefore, had been included into official catalogs).

Update of Regional Seismic Regimes

From the geological viewpoint, the territory of Northern Eurasia includes two types of structures: (1) four large platforms of different age, characterized by relatively low and scattered (diffused) seismicity (East European, Turanian, West Siberian, and Siberian); (2) the series of orogenic regions of extremely high seismicity (Iranian–Caucasian–Anatolian, Central Asian, Altai–Sayan–Baikalian, Kuril-Kamchatkan, and others). The seismic regionalization used during construction of the GSZ-97 and its updated version of GSZ-97* is illustrated by Fig. 8. The graphs of average annual recurrence of earthquakes with different magnitudes, on the basis of the SEC as of its 2010 update, are given in Fig. 9. Along the abscissa axis, magnitude values are plotted (with ± 0.2 interval and with 0.5 ΔM step). The ordinate axis indicated average annual number N_M of earthquakes with $M \geq 4.0$ in the main seismoactive regions of Russia. During seismological parameterization of the updated ESZ model, the Altai–Sayan–Baikalian region was divided into two subregions along the 104° E meridian. It is seen that the graph of the Kuril–Kamchatkan region is plotted above of all others (4.1 in Fig. 8); the second highest graph is that for the Iranian–Caucasian–Anatolian region (1.1 in Fig. 8). The lowest activity is characteristic for the subregions of the European part of Russia.

Update of the Earthquake Source Model

During the works on updating the GSZ-97 maps and making their updated version GSZ-97*, the most attention was paid to the European part of Russia, which is characterized by high population density and where many nuclear objects are located. In particular, as has been shown above, the $M = 4.8$ seismic event of December 20, 1954 was excluded from the catalog (explosive blast). In its order, this is reflected in the LDF-model of ESZ. In particular, the seismodomain including the Voronezh Crystalline Massif was slightly modified. Previously, in the framework of the GSZ-97, it

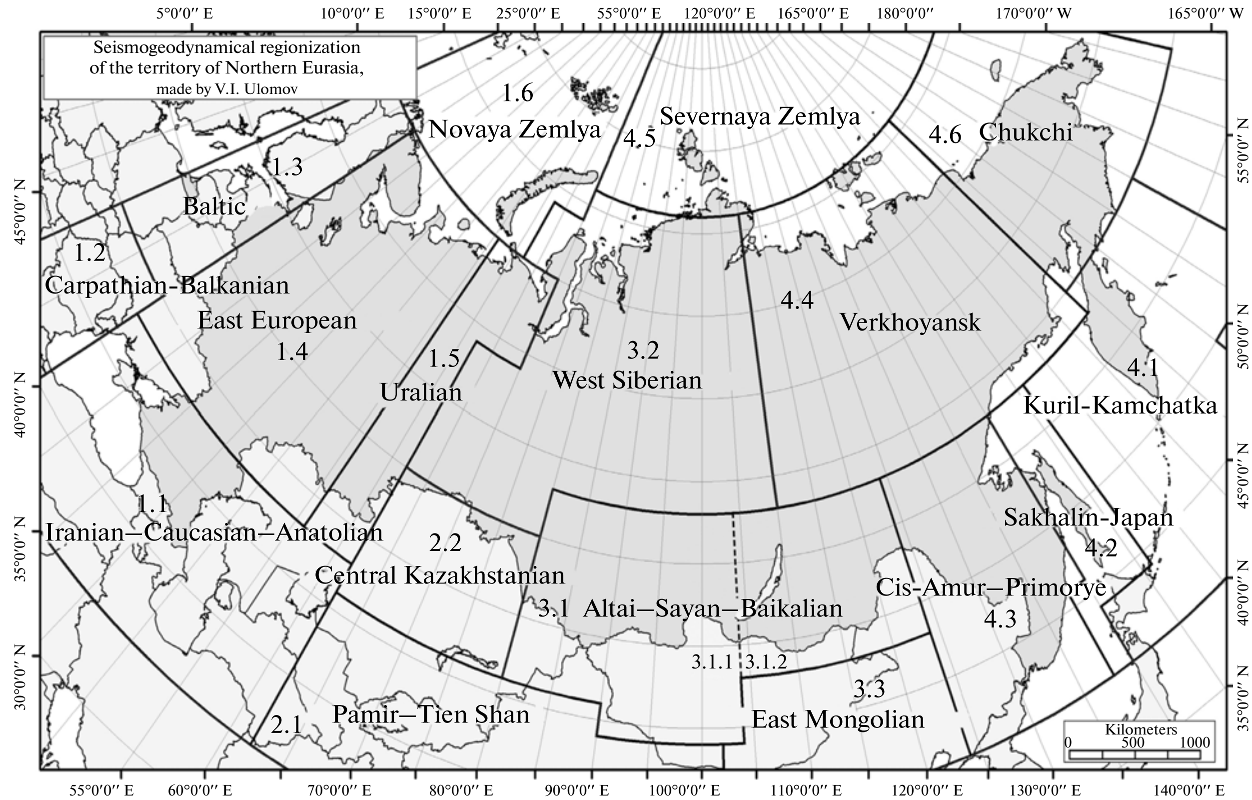


Fig. 8. Seismogeodynamical regionization of the territory of Northern Eurasia, made by V.I. Ulomov.

was estimated by the maximal possible earthquake of $M_{max} = 5.0$. Now its potential is set at $M_{max} = 4.5$; this was made because of the local $M = 3.8$ earthquake (2000 Nikol'skoe earthquake), whose value was averaged to $M = 4.0$ in the SEC and $M = 0.5$ then was added, in accord with the modern international technique of seismic hazard estimation.

A certain update was implemented for two SLs in the Middle Urals: they slightly misfit the newly discovered faults, however they remained of the same $M_{max} = 6.0$ and seismic regime. The seismolineament in the Kandalaksha Bay was reduced by one segment (southeastern one), but $M_{max} = 6.5$ remained the same. In Koryakia, one seismolineament of $M_{max} = 7.5$ was slightly shifted westwards in parallel to its previous orientation. The boundaries of the Uralian region were updated in comparison to the previous ones; two domains with the adequate parameterization were added in the western part of Kaliningrad Oblast, which was completely omitted (due to technical reasons) in the GSZ-97 maps included into the modified version (2000) of the SNiP II-7-81* (Ulomov, 2008).

The updated version of the ESZ model for GSZ-97* is given in Fig. 10 and, together with the other information, is presented on the website of the IIS Seismic Safety of Russia (see below). With the supplemented earthquake catalog and modifications of the ESZ model taken into consideration, the seismic regimes of all regions was revised (see Fig. 9) and then reflected in parameterization of the LDF-model of ESZ for GSZ-97*.

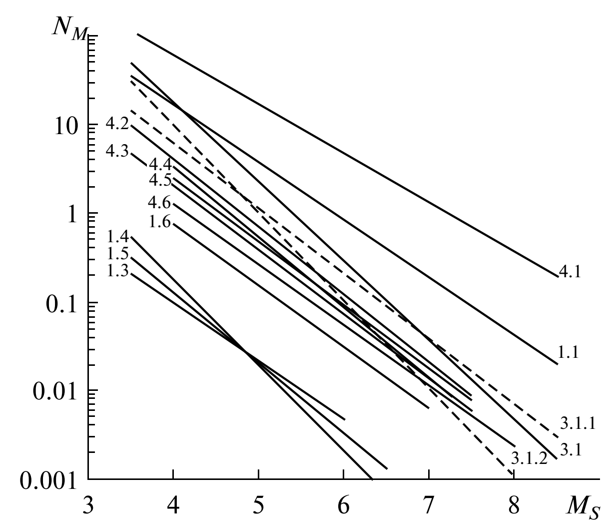


Fig. 9. Graphs of average annual recurrence N_M for the earthquakes of different magnitudes M_s in the regions and subregions of Russia, denoted by digit codes (see Fig. 8).

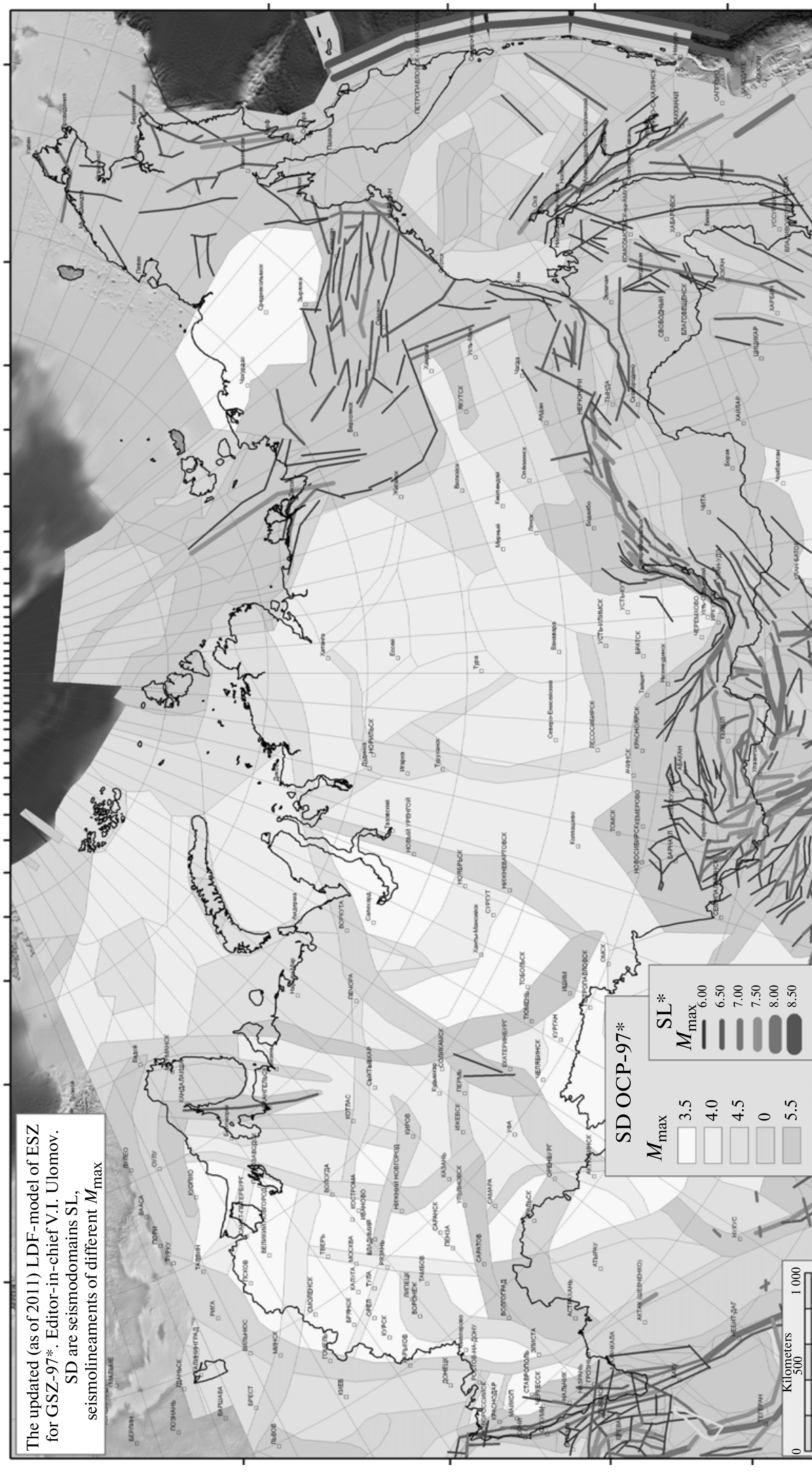


Fig. 10. The updated (as of 2011) LDF-model of ESZ for GSZ-97*. Editor-in-chief V.I. Ulomov. SD are seismodomains; SL, seismolineaments of different M_{max}.

Table 2. Probability (P) of 90% not exceeding of the seismic hazard during t years for the maps with recurrence period T

Parameter	Probability of 90% not exceeding during t years					
t, years	10	50	100	250	500	1000
T^*, years	95	475	975	2475	4975	9975
T, years	100	500	1000	2500	5000	10000

Expansion of Probabilistic Estimates of Seismic Hazard

When constructing the updated GSZ-97 maps, the set of probabilistic maps was expanded by adding two maps for recurrence periods of 100 and 2500 years. This was caused by a number of circumstances, including the fact that seismic effects cannot be adequately assessed for some kinds of building objects; another important argument for this was the suggestion that for the purpose of civil and industrial building, the maps for periods T of 100, 500, and 2500 years will be used instead of those for 500, 1000, and 5000 years. The maps for periods of 100, 500, and 2500 years can be referred to as three categories of responsibility for building objects (lowered, normal, higher) in terms of the new Federal Law entitled "Technical Rules for Safety of Buildings and Facilities" (*Federal'nyi*..., 2009) and the Urban Development Code of the Russian Federation (*Gradostroitl'nyi*..., 2004). These periods do not contradict the international recommendations. However, it may be noted that the United States demonstrate a tendency to increase the estimate of seismic hazard by transition from maps of $T = 500$ years to those of $T = 2000$ years.

Table 2 presents the probability values of 90% not exceeding seismic hazard during different time intervals t. Here, T^* means the model period of seismic effect recurrence, providing a 90% non-exceeding value; T, the more usual, averaged values of these periods.

Differentiated Estimate of Seismic Hazard

Traditionally, since 1937 (i.e., since the Seismological Institute, Academy of Sciences of the USSR, now IPE RAS, constructed the first normative map of seismic zoning of the country—for the first time in the world), the estimation of seismic intensity has been made by utilizing the macroseismic effect expressed in integer (averaged) units of the MSK-64 macroseismic scale (GOST 6249-52). However, during strong earthquakes, these values can be referred to as a quite broad dynamical range of seismic effects; this, in its order, often led to over- or underestimation of expected seismic hazard. Ultimately this affected the quality and costs of seismic engineering works.

After changing the paradigm in the GSZ-97 and constructing the set of dynamically changing maps instead of one, a series of previously hidden technical challenges emerged and complicated the builders' work on the seismic safety provision for buildings and facilities. For example, it has been found that one unit step in gradation of the macroseismic scale often caused seeming coincidence of macroseismic effect in the same territories for two and sometimes all maps of the GSZ-97 set. The cause of these "coincidences" is explained by Fig. 11, which shows the voluminous ESZ model with arbitrary GSZ-97 maps (A, B, C, D) above it; the maps depict different recurrence periods for the events of 6, 7, and 8 on the MSK-64. In the above maps the coinciding values of seismic effect for the same arbitrary settlements in the A, B, and C maps is indicated. As is seen, the combinations of intensities for this instance were 6–7–7, 6–7–8, and 6–6–6 on the MSK-64.

Note that such problems were not faced previously in the practice of seismic zoning; moreover, it could not appear at all because only one map was used and when designing the objects of different degree of importance specialists used so called "coefficients of seismicity" from SNiPs to take the seismic hazard into account. Now they have a set of probabilistic maps instead of one deterministic map, and these maps are directly purposed to provide seismic safety of objects referring to different categories of importance and life, therefore there is no need to use any coefficients. However, the developers of the updated SNiPs found the solution and applied modified coefficients of seismicity. In order to avoid "the same" estimates of seismic hazard in two or more maps for the same point, the table of modified coefficients has been included into the project of SNiP II-7-81* (SNiP 2010); these coefficients take into account seismic effects, depending on the combination of model seismic intensity from the A, B, and C maps (Aizenberg, 2011).

It is also obvious that "coinciding" estimates of intensity in GSZ-97 maps is produced by using the integer units of intensity and the inadequately big extent of zones of supposedly the same intensity. If to express seismic intensity in GSZ maps through half-points (i.e., with the step of 0.5 units of intensity), then the number of coincidences will significantly be reduced; in the case of a 0.1 unit step, coincidences can disappear entirely. Note that even application of a half-unit gradation set as a normative would be effective in an economic sense as well. The maps of 0.1 units can be assumed as a reference source when

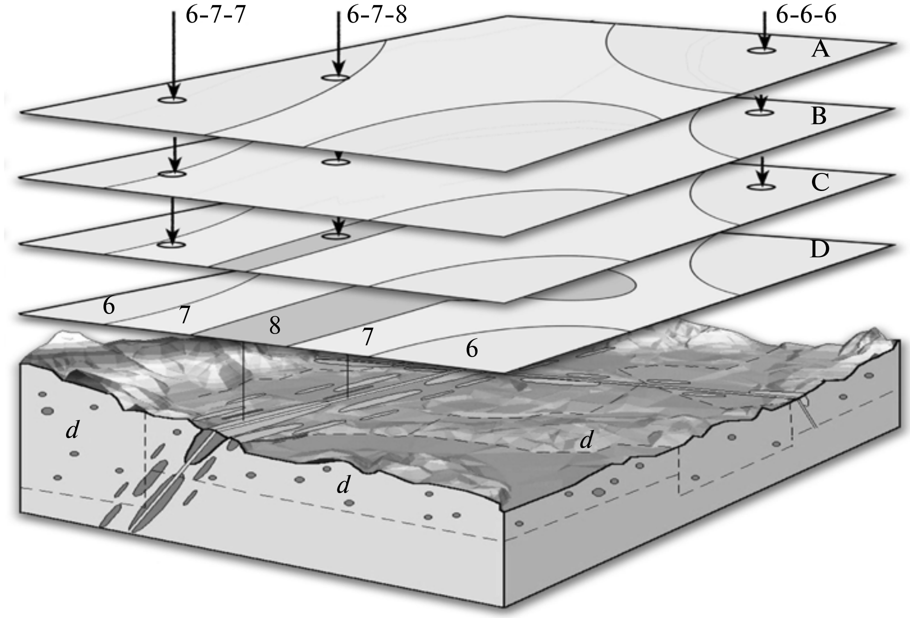


Fig. 11. Illustration of coincidences in intensity units for the same points on the maps constructed on the basis of the same earthquake source model but for different recurrence periods. See explanations in the text.

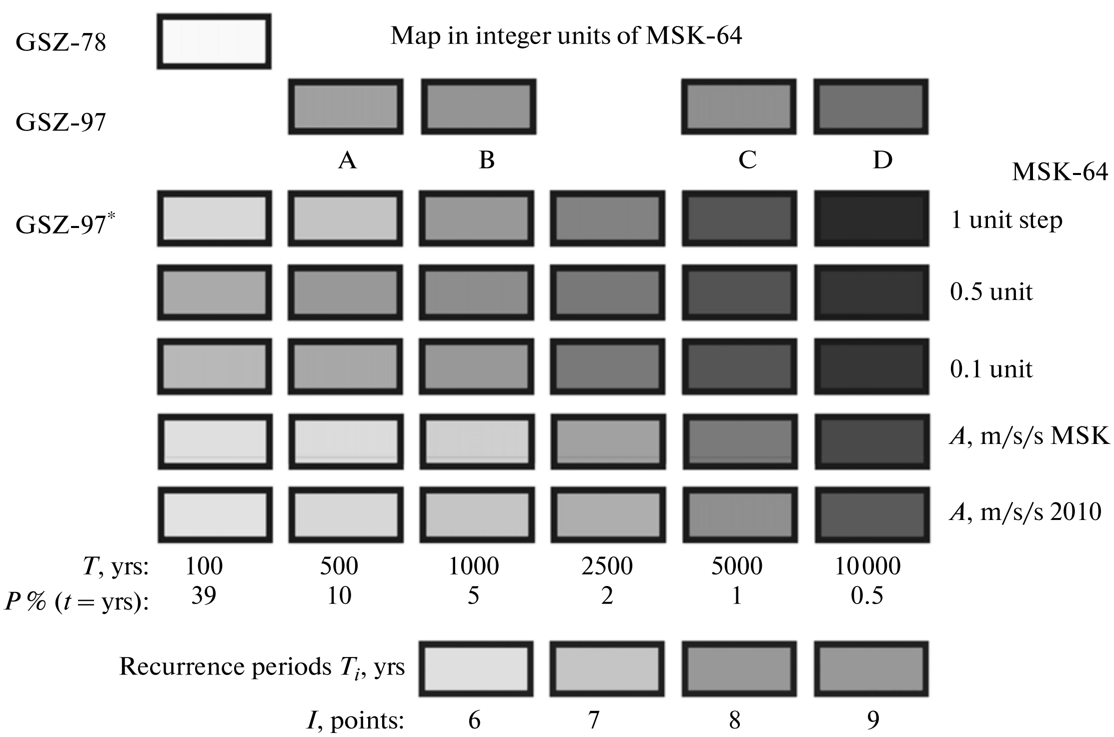


Fig. 12. Scheme of the set of maps given in digital form in the framework of the IIS "Seismic Safety of Russia" (see explanations in the text).

SMZ works and studying the fine structure of a macroseismic field. The maps showing the continuous (smooth) representation of seismic effect will not have any coincidences at all.

As to the acceptable risk that the model value of seismic effect will be exceeded, the updated GSZ-97* maps is approximated to the international standards (Eurocode-8 etc.) in this sense.

Expansion of the GSZ-97 Set of Maps*

Taking into consideration the mentioned above and other modifications, the GSZ-97* set of maps was constructed; it includes 34 digital maps (digital layers), which are hosted on the web-portal of IIS "Seismic Safety of Russia." Figure 12 schematically shows the GSZ-78, GSZ-97, and GSZ-97* sets of maps; the first two are presented in integer units of intensity, while the last one have fractional units (0.5 and 0.1) as well for all recurrence periods. The GSZ-97* set also comprises four maps showing recurrence periods for events of 6, 7, 8, and 9 on the MSK-64. Figure 13 exemplifies one of the maps from the GSZ-97* set, compiled for the period $T = 2500$ years with a half-unit step.

Another important improvement of the GSZ-97* set is construction of maps showing seismic effects in terms of peak ground accelerations (Figs. 14, 15). Notwithstanding, it has been noted that the absence of an efficient service for ground acceleration recording in Russia does not enable application of PASH routines in terms of ground acceleration with sufficiently valid results. Nevertheless, it has been permitted, with certain limitations, to calculate and map the amplitude estimates of seismic effects on the basis of their recalculation from fractional unit estimates, as it has been made previously by the IPE RAS in the framework of GSHAP (Ulomov, 1999). Additionally, the suggestion by A.A. Gusev (2011) to construct the GSZ maps in terms of peak accelerations for hard rock (traditionally, in Russia it was made only for the second category of grounds—see SNiP II-7-81*).

At present, it is commonly accepted that the MSK-64 scale significantly underestimates seismic hazard and probably will be changed to the ShIZ-2010 scale, which was designed and suggested under the leadership of A.A. Aptikaev in 2010 (Aptikaev, 2010; *Shkala* ..., 2011; Aptikaev and Erteleva, 2005). With respect to this, the GSZ-97* set contains the ground acceleration maps of two types, utilizing the MSK-64 and ShIZ-2010 scales.

ON THE SEISMIC ZONING OF THE NEXT GENERATION

ESZ Map Montages for GSZ-2012

As has been said above, when constructing the GSZ-2012 set of maps, the GSZ-97 methodology is kept for identifying and seismodynamical parameterization of the LDF-model of ESZ, as well as the probabilistic approach to estimation of seismic hazard.

For constructing the maps of the next generation, two versions of ESZ models have been developed. Version 1 (Fig. 16) almost completely (excluding the platform territories) reproduces the domain component developed in 1992–1995 by V.G. Trifonov and N.V. Shebalin for GSZ-97 maps and then used in the GSHAP global map (Ulomov, 1999). V.G. Trifonov recommended revising the domain structure of the European part of the country and West Siberia due to his denying the previous models of active faults in these territories. Thus, the geometry and contents of the previous domains were changed by zones suggested by V.I. Makarov (however, this work was not completed due to Makarov's death).

Version 2 (Gusev et al., 2011) is given in Fig. 17. Resulting from discussions at the meeting of the working group on construction of GSZ-2012 maps, this zoning model for geodynamically active zones has been accepted as fundamental and the most suitable. It was based on the multiannual studies of geodynamical settings, under which neotectonic objects had been formed, and on the map of 2001 ("Scheme of Tectonic Zoning of Russia," M 1 : 5000000) constructed by G.S. Gusev with colleagues. For the purposes of GSZ, this structural zoning was the basis. As to the zoning of geodynamical activity in the territory of the Russian Federation, it was developed by distinguishing nine classes of neotectonic activity, whose geological-geophysical criteria are based on the well-known classification principles and terminology of geodynamical analysis.

For comparison purposes, Fig. 18 presents the fragments of both versions of ESZ models for the European part of Russia. Note that the authors of version 1 had the whole catalog of earthquakes in Northern Eurasia and used it for correction and parameterization of distinguished domains. It is also important to emphasize that the authors of version 1 had not accessed the SEC, so their geodynamical constructions were more objective. However, further comparison of geodynamical activity parameters (comparison of classes) between those in version 2 and real seismicity in the territory of the country has shown quite good correlation; this can be seen in Fig. 19 in the form of a weighted average dependence between maximal magnitudes $M_{\max}$ and $M^*_{\max}$ for earthquakes that occurred previously in every zone of different classes K of geodynamical activity.

Seismic lineaments, which are given in the map montages of every ESZ model (see Figs. 17, 18) and mostly taken from the GSZ-97 database, have been updated in part. The works on their identification and parameterization are still lead by the author. The studies in this field are carried on with the regional specialists participating (V.I. Ulomov, A.A. Nikonov, and V.G. Trifonov for the European part of Russia; A.A. Gusev, A.I. Kozhurin, and V.N. Smirnov for the Russian Far East; L.P. Imaeva, V.S. Imaev, and A.V. Chipizubov for Siberia). In the end of the paper, the complete staff of the working group on construction of the GSZ-2012 maps is given.

For a more complete and effective discussion by the scientific society, both versions and the initial data were published on the web-portal of the IIS "Seismic Safety of Russia" (Figs. 20–23) (http://seismorus.ru/).

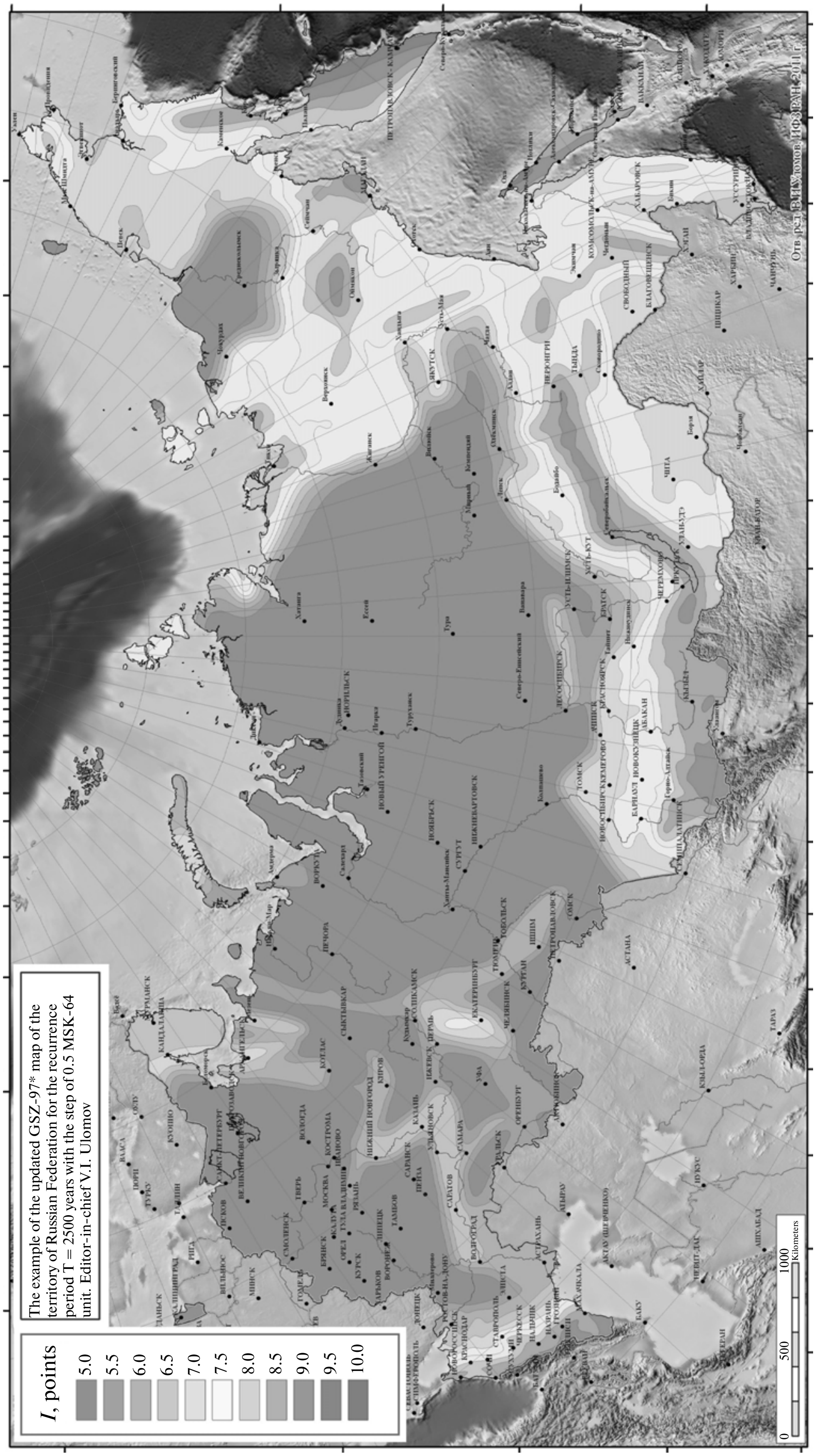


Fig. 13. The example of the updated GSZ-97* map of the territory of Russian Federation for the recurrence period $T = 2500$ years with the step of 0.5 MSK-64 unit. Editor-in-chief V.I. Ulomov.

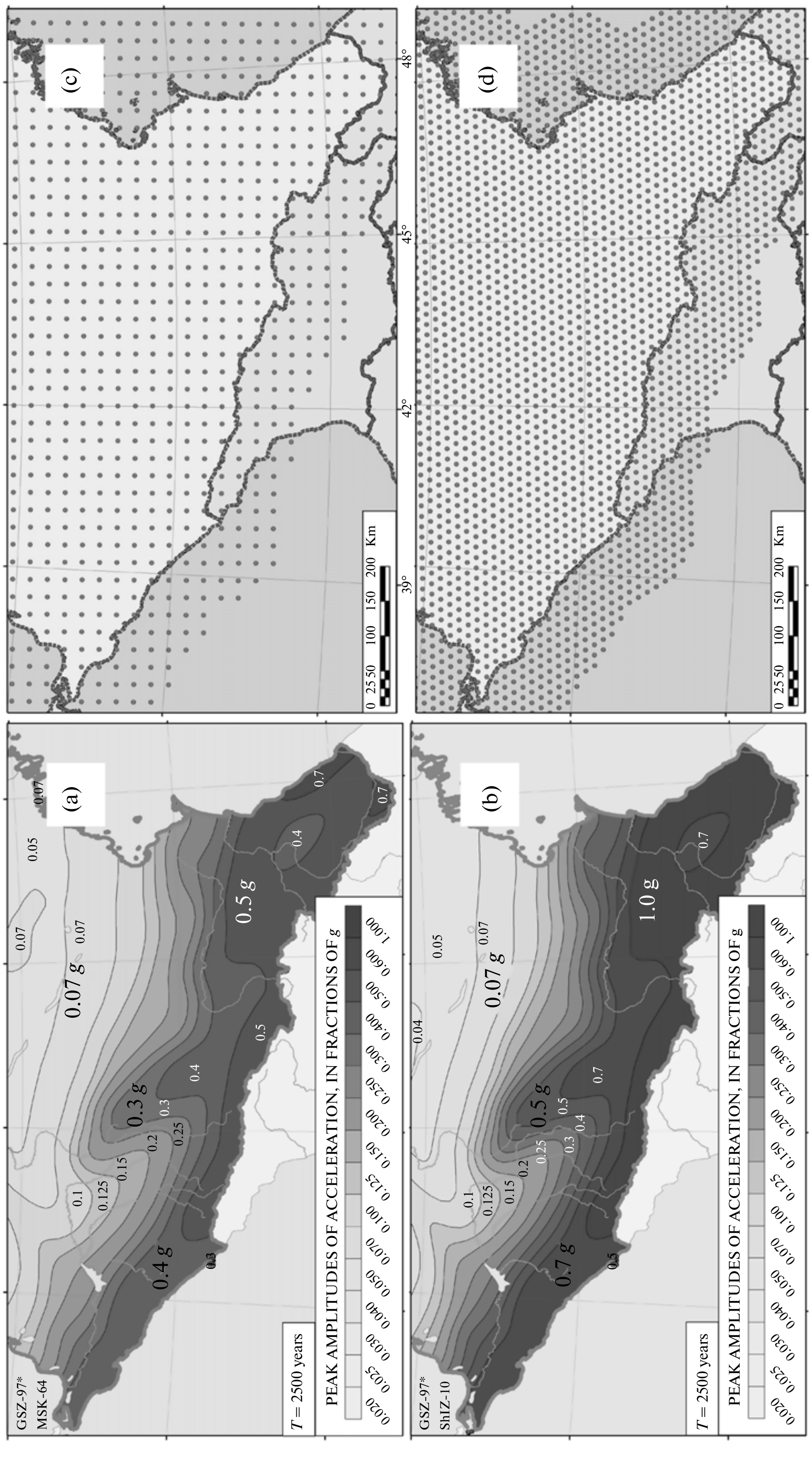


Fig. 14. Fragments of the GSZ-97* maps (the region of North Caucasus is shown) for the recurrence period $T = 2500$ years, presented in peak ground accelerations calculated on the basis of the MSK-64 scale (a) and the project of the ShIZ-2010 scale (b). Fragments of regular meshes on whose basis the shaking of the North Caucasus region was calculated for the GSZ-97 (c) and GSZ-97* (d) maps.

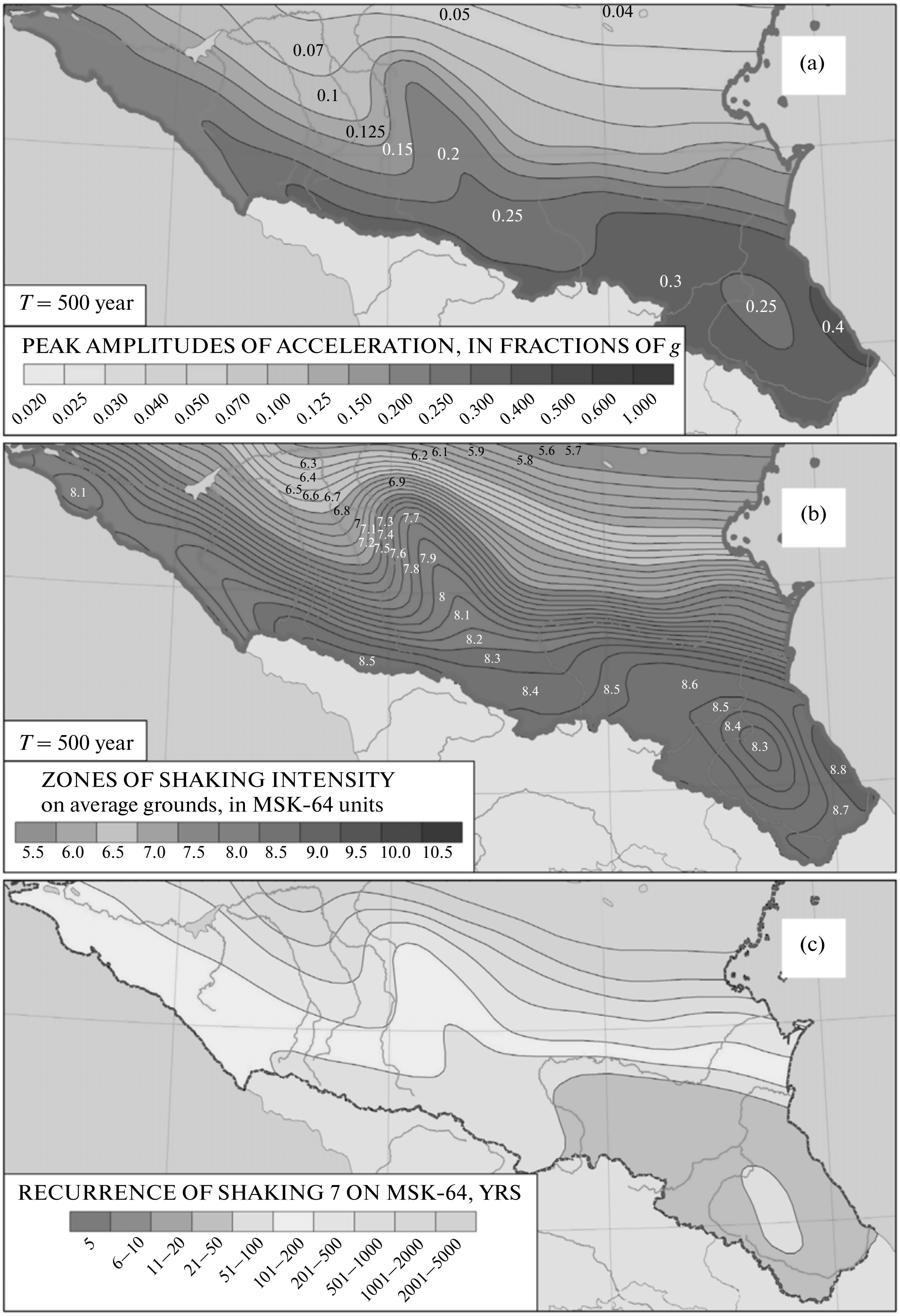


Fig. 15. Fragments of three types of the GSZ-97* maps (the region of North Caucasus is shown), presented in fractions of gravity acceleration g (a), in half-units of seismic intensity (b), and in recurrence periods of earthquakes of 7 on the MSK-64 (c). Made by V.I. Ulomov.

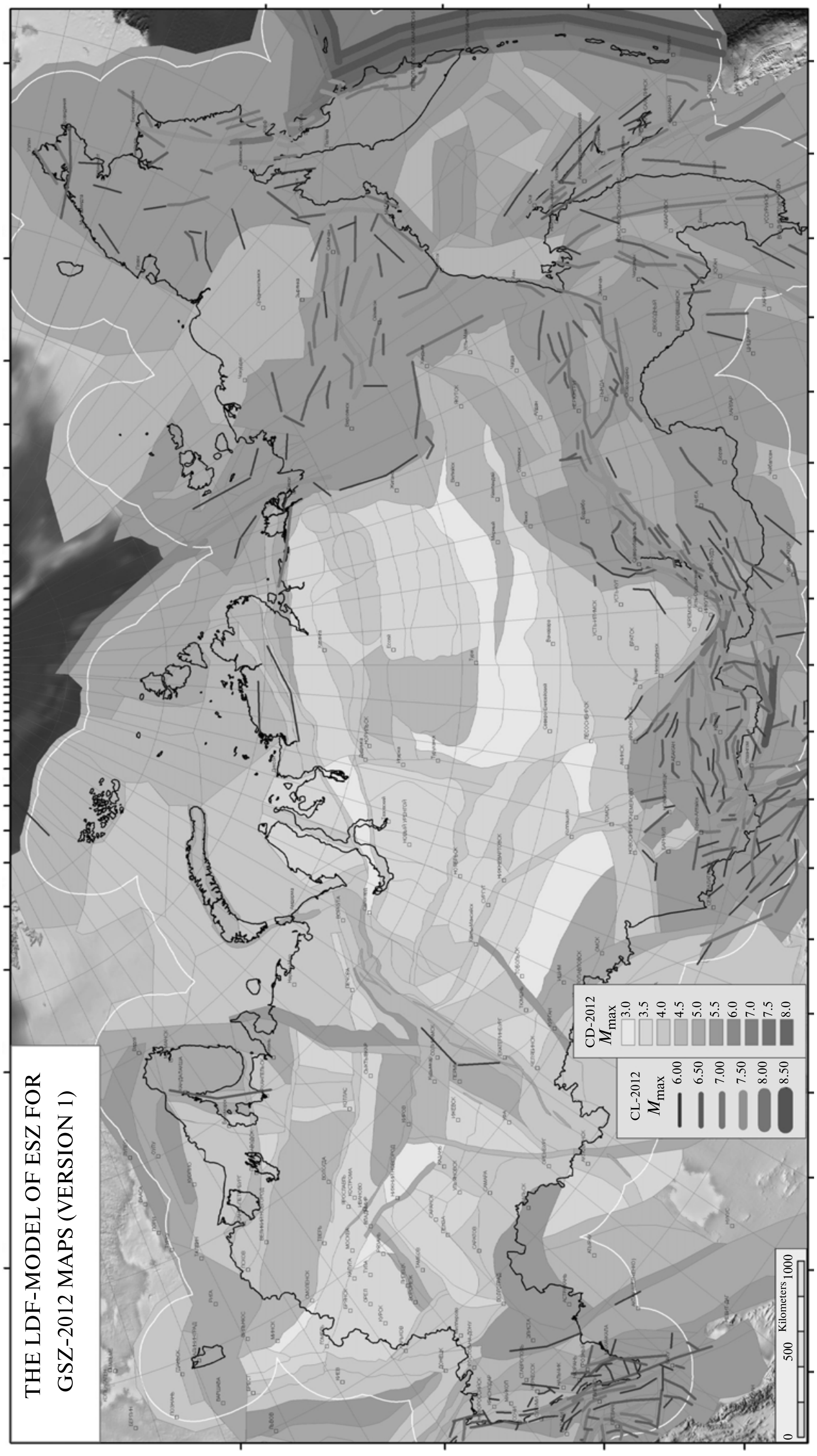


Fig. 16. The LDF-model of ESZ for GSZ-2012 maps (version 1). The seismoactive zones that geometrically correspond to domains (model by V.G. Trifonov and N.V. Shebalin) are parameterized on the maximal earthquake magnitudes known in their limits as of 1995. The information on lineaments drawn above domains (data are edited by V.I. Ulomov) was not used. The white contour confines the territory where active fault tectonics were studied.

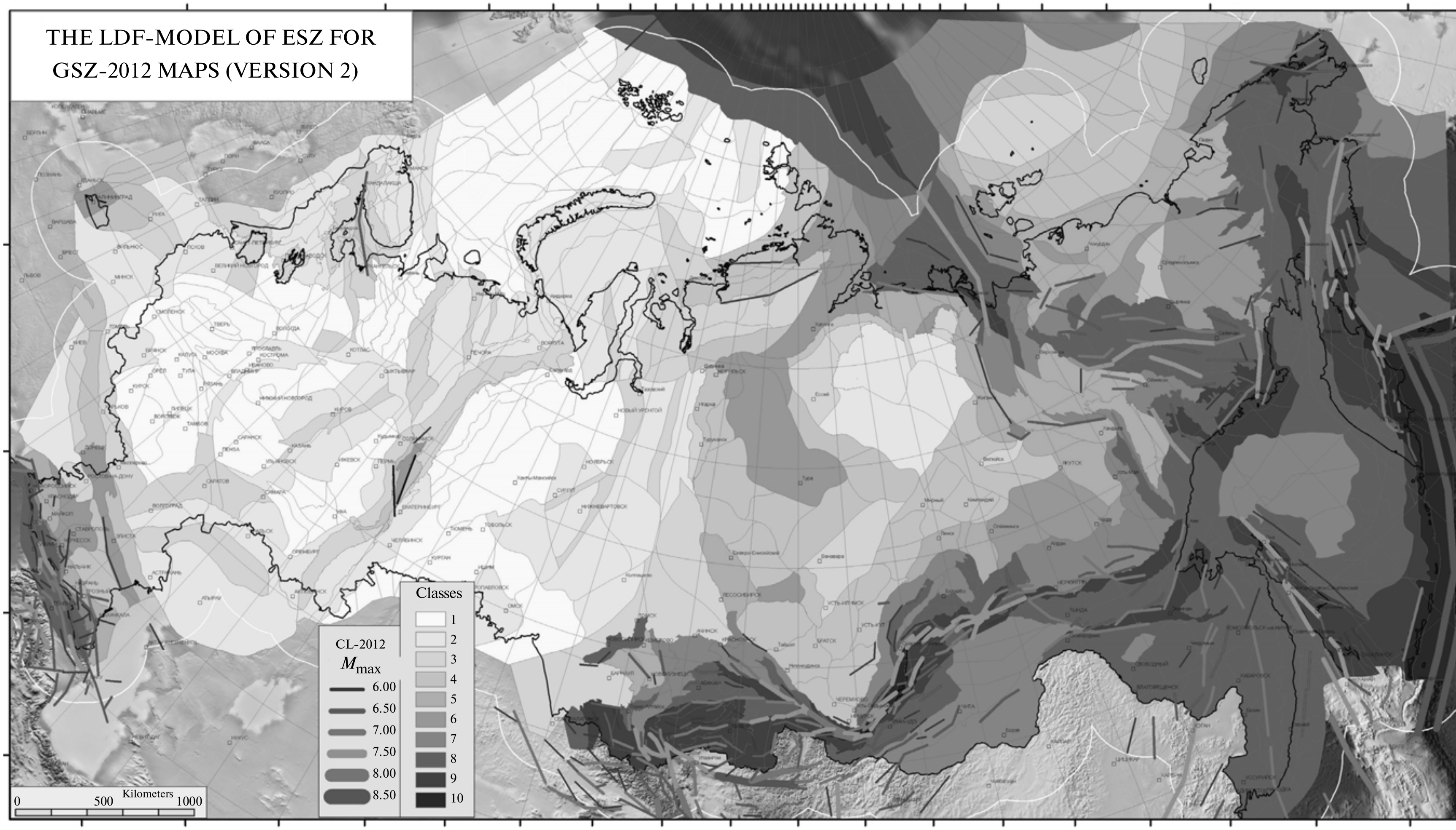


Fig. 17. The LDF-model of ESZ for GSZ-2012 maps (version 2). The zones geometrically correspond to domains and are parameterized on classes of their geodynamical activity (model by G.S. Gusev and L.P. Imaeva). Information about occurred that earthquakes and seismolineaments was not used.

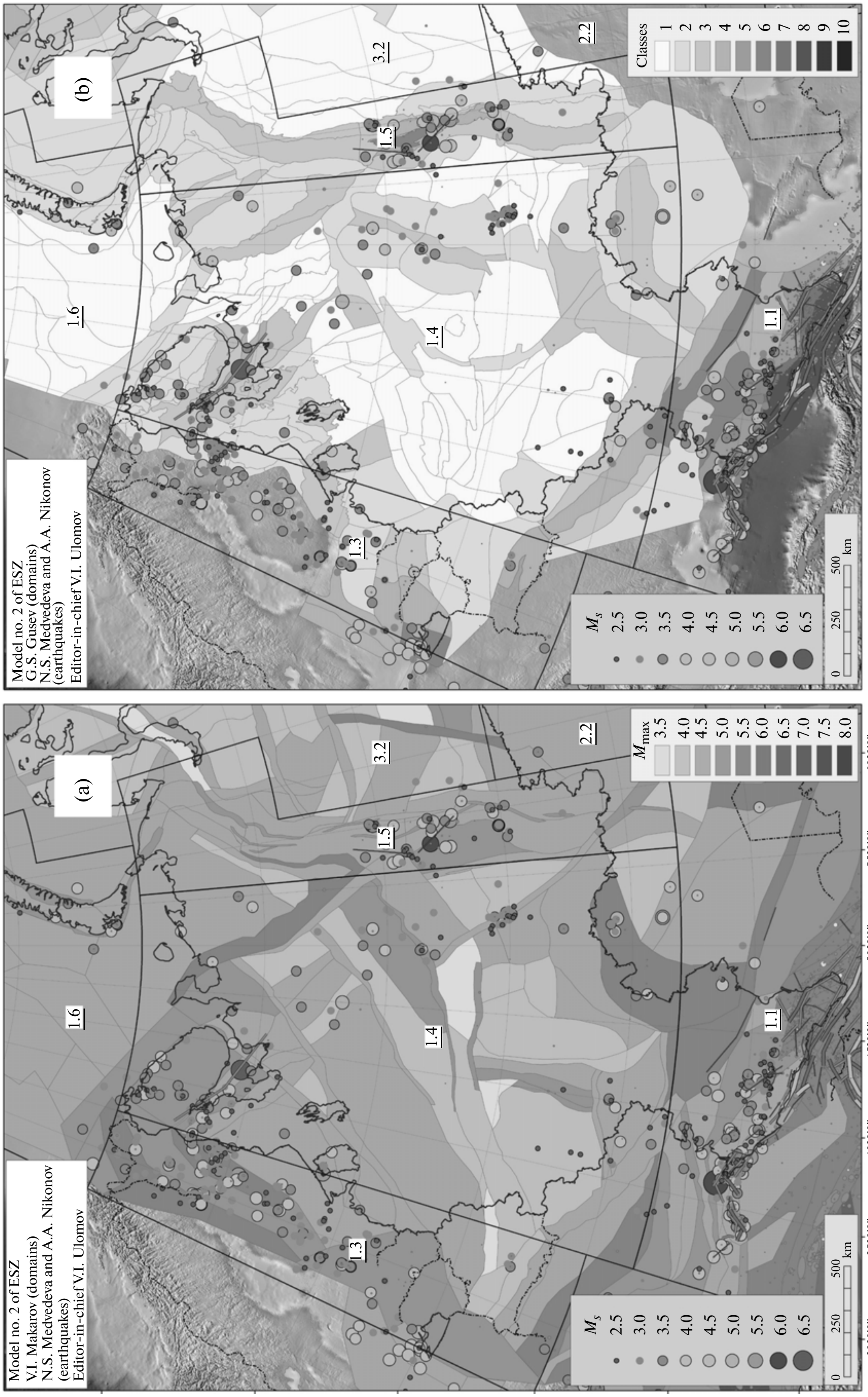
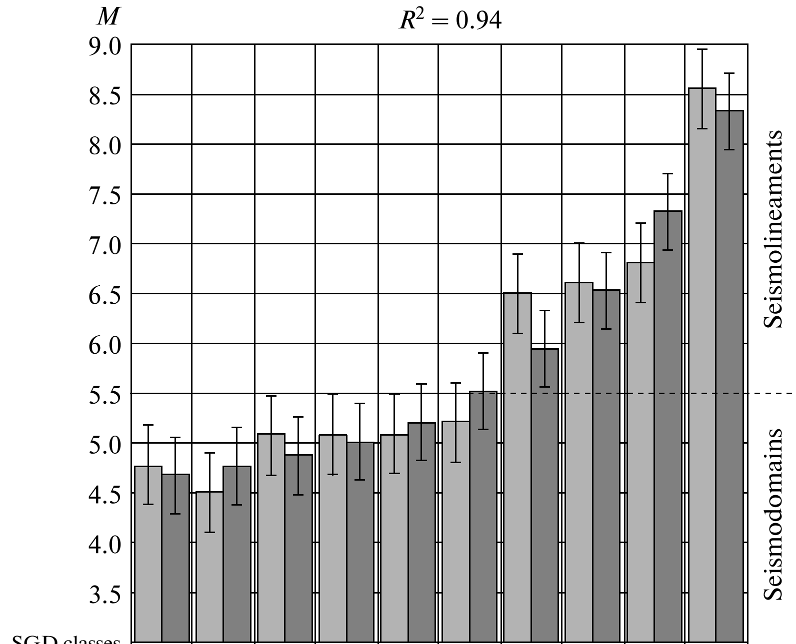


Fig. 18. Fragments of the model versons 1 (a) and 2 (b) for the ESZ of the European part of Russia with local seismic events denoted. The domain model was developed by V.I. Makarov (a) and G.S. Gusev (b); data on earthquakes were compiled by N.S. Medvedeva and A.A. Nikonov; editor-in-chief V.I. Ulomov. Epicenters of the known earthquakes are denoted by circles of different grayscale tones depending on magnitude.

$$M^*_{max} = 0.0052K^3 - 0.00291K^2 + 0.1492K + 4.5508$$

$$R^2 = 0.94$$



SGD classes K	1	2	3	4	5	6	7	8	9	10
M_{max}	4.8	4.5	5.1	5.1	5.1	5.2	6.5	6.6	6.8	8.6
M^*_{max}	4.7	4.8	4.9	5.0	5.2	5.5	6.0	6.5	7.3	8.3

Fig. 19. The probable relationship between seismogeodynamical (SGD) classes (K) in the model of version 2 and maximal magnitudes (M_{max}) of earthquakes within their limits. This histogram shows the distribution of maximal magnitudes. In accord with the LDF-model of ESZ used in the GSZ, the part of histograms above the horizontal dashed line characterizes magnitudes of lineaments located within the ESZ.

Among the number of functions, the IIS provides effective double-sided communication and feedback channels. It incorporates other databases of vector and raster spatial data on the territory of the Russian Federation, seismic regionization of the country, locations of seismic stations, and other important information.

The IIS web-portal represents special information in seven major subjects, given in the respective pages: Main, Earthquakes, Seismic Hazard, Seismic Risks, Building, Norms, and Information. The maintenance system enables us to update the IIS, to make changes in its structure, and to edit the content by an administrator. To provide safety of content, access isolation is made to both the portal as a whole and its subdivisions and functions.

The IIS portal enables one to organize the forums for discussions (in particular, to discuss the results of DSZ and SMZ); these forums should be set as “private” or “confidential,” otherwise they cannot be controlled and discussion would not be effective.

DISCUSSION

The requirement of a substantial update for the model of predicted seismic effects emerged several years ago and became obvious; construction of new seismic zoning maps for an adequate utilization in building norms has also been required for several years.

The new approaches to construction of the updated GSZ-97* set of maps and subsequent GSZ-2012 one have been discussed and affirmed at a series of working meetings with participation of heads and assigned persons on perfection of regulatory norms in construction, e.g., at the East Siberian Regional Research and Practice Conference on Seismic Safety on Construction (held on December 13–14, 2011 in Irkutsk), the following decisions were made among the others:

(1) Approve the concept and methodology for studies devoted to the update of GSZ of the territory of Russia, led by the Russian Academy of Sciences (RAS), and to construction of a set of different probabilistic GSZ maps of the next generation. These maps characterize different degrees of seismic hazard and, in addition to the traditional intensities of seismic effect in MSK-64 units, depict the expected values of peak ground accelerations.

(2) In order to optimize the studies on GSZ, DSZ, and SMZ, the important point is application of PASH and representation of the seismic effects intensity in both integer and fractional units; the latter is crucial for both SMZ, where the influence of real ground con-

Fig. 20. One of the main web-pages of the IIS "Seismic Safety of Russia"—work with the earthquake catalog of Northern Eurasia is illustrated.

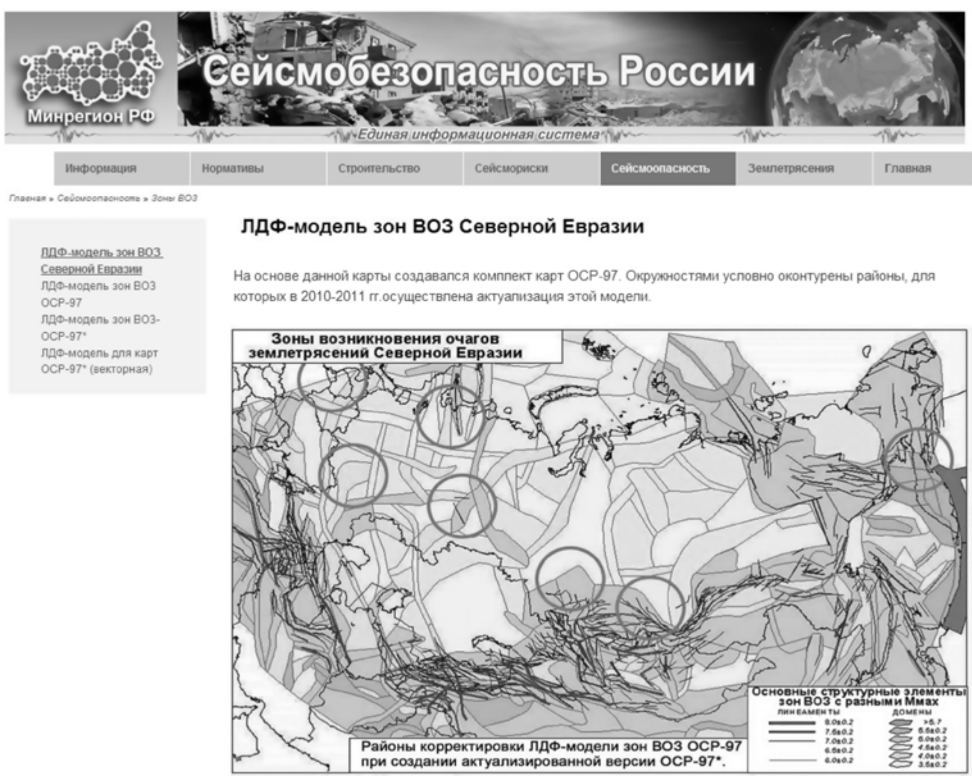


Fig. 21. The web-page of the IIS "Seismic Safety of Russia" depicting the LDF-model of ESZ for GSZ-97 (circles denote the sites, on which the data have been updated in the GSZ-97*).

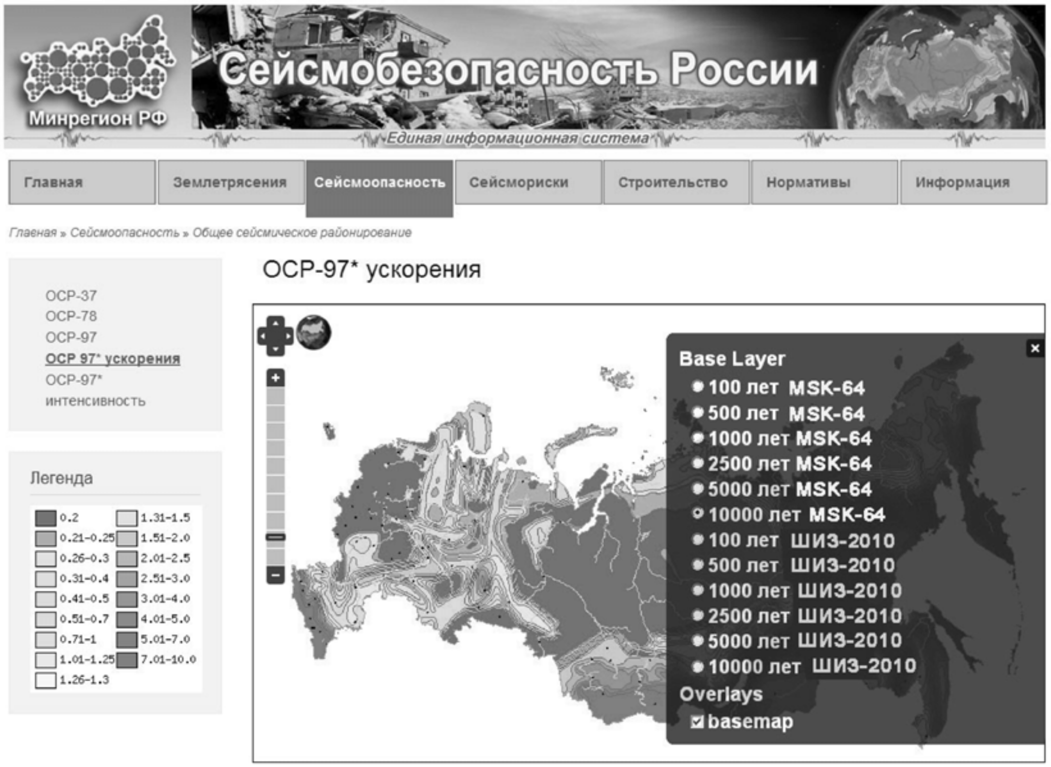


Fig. 22. The web-page of the IIS "Seismic Safety of Russia" with the GSZ-97* maps available to select: peak ground accelerations for two scales and six recurrence periods.

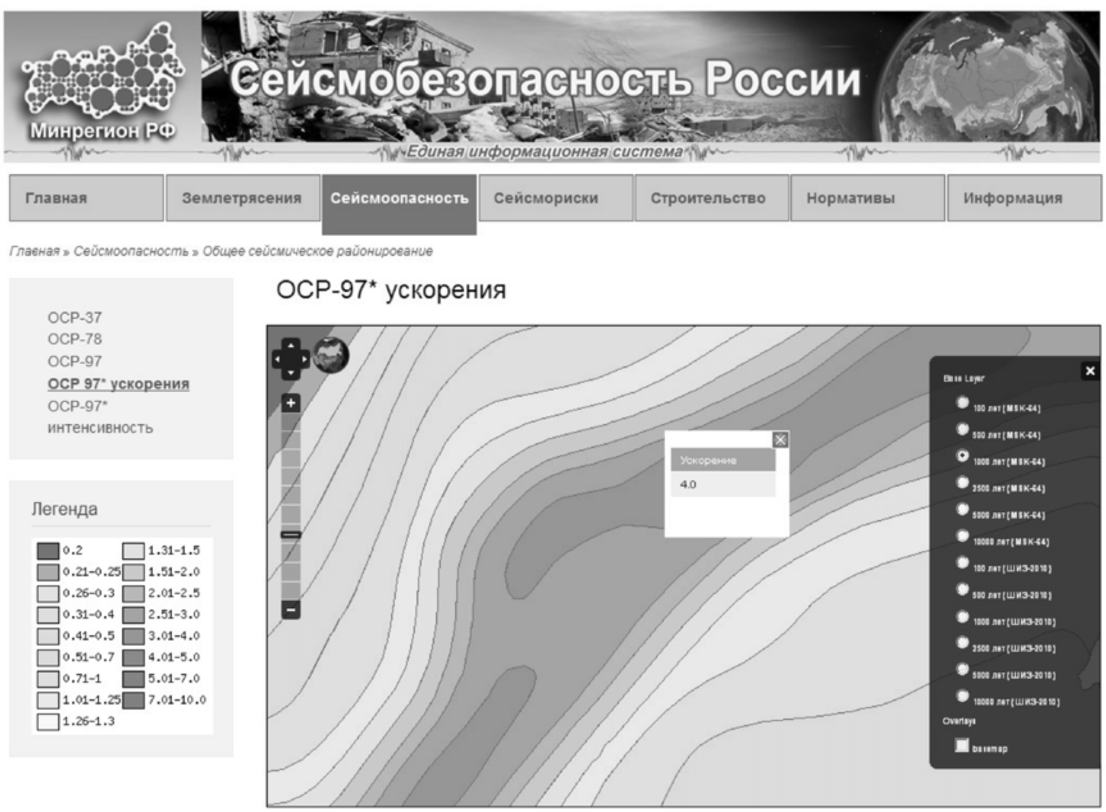


Fig. 23. Work with the zoomed fragment of the Baikalian region map (IIS "Seismic Safety of Russia").

ditions on seismic effects is taken into account, and for representation of seismic effects in terms of ground accelerations.

(3) Consider the coordination and cooperation in this field between seismological and engineering institutions and specialists as absolutely required.

(4) When developing the new edition of general seismic zoning maps (GSZ-2012), the project of these maps must be discussed with a number of specialists in the fields of seismology and seismic engineering. The scientifically sound model parameters of seismic effects, based on the available data for the territory of the Russian Federation, should be represented by respective institutions, including the IPE RAS, Institute of the Earth's Crust, RAS, Geophysical Survey, RAS, Sergeyev Institute of Environmental Geoscience, RAS, JSC PNIIS with participation of Kucherenko Central Research Institute for Building Constructions (CRIBC).

The working meeting devoted to coordination of studies on seismic zoning and seismic engineering was held on December 20, 2011, in the CRIBC, chaired by L.S. Barinova (the Chairman of the Interindustry Council on Technical Regulation and Standardization in the Building Complex of Russia). At this meeting, the author reported about the studies on the GSZ update and on the requirement to present agreed design specifications for further development of GSZ-2012 maps in advance; note that the latter point had been reported for the first time at the meeting of the Expert Commission on Seismic Engineering in December 2009.

The same problem arose again at the joint meeting held on January 19, 2012 in the IPE RAS, with working groups on GSZ and SNiPs participating (the workshop "Topical Problems in Development of Methods for Setting the Model Seismic Effects in Regulatory Documents"). Here, the GSZ-2012 working group member, A.A. Gusev (Institute of Volcanology and Seismology, Far East Branch, RAS), reported the details on the subject. Below, the list of the main tasks formulated by A.A. Gusev (2011a, 2011b) and intended for solution in the nearest future is presented. It is clarified in the end of every task, to which subject these belong (GSZ, SMZ, SNiP, seismic engineering in whole):

(1) Confirm the requirement of updating the regulatory norms on standard seismic loads in the directions of GSZ–SNiP and SNiP–GSZ with respect to engineering seismology achievements of the recent decades.

(2) Keep the standard relationship between the MSK-64 intensity unit and ground acceleation only for hard rocks. Revise the coefficients of relationship between the MSK-64 intensity unit and ground acceleration, assumed in SNiP by increasing the acceleration value A approximately 1.5–1.7 times ($A = 0.30$–0.35 at 8 on the MSK-64). Exclude the strong dependence of intensity and ground acceleration for non-hardrock grounds (seismic engineering, SNiP).

(3) Revise the correlation between lithological composition and peak ground acceleration, assumed in the SNiP. The relationship used presently implies a double acceleration at a four-fold decrease in shear wave velocity in ground. Such a relation is reasonable for maximal velocities, but must be completely revised for accelerations. For example, when choosing the version of nonlinearity account by Eurocode-8, the coefficients for the used categories of ground (first, second, and third; see SNiP II-7-81*)–1, 2, 4—should be changed to approximately 1, 1.2, and 1.15, respectively (seismic engineering, SMZ, SNiP).

(4) Abandon the use of peak acceleration values in average ground type (category 2) as the main amplitude parameter and apply the peak acceleration value in hardrock (category 1) instead (seismic engineering, GSZ, SMZ, SNiP).

(5) Abandon the use of normalizing the dimensionless response spectra to peak acceleration value in a given ground type. Following the principles of Eurocode-8, accept the normalizing of the response spectra to peak acceleration value in hardrock (category 1); with respect to this, consider the term "coefficient of dynamicity" obsolete and use the term "normalized response spectra" instead (SNiP, SMZs).

(6) Abandon the characteristics of the grounds based on frequency-independent parameter "update of intensity" and change it to the principle of spectral characteristics of grounds. The coefficient taking into account the effect of ground layer (coefficient of ground) should depend on vibration period (natural frequency) of a building (SMZ, SNiP).

(7) Abandon the indirect use of hypothesis about nonlinear behavior of non-hardrock grounds at high values on the MSK-64 scale. Affirm the importance of nonlinear behavior of non-hardrock grounds for a more valid estimation of seismic loads on buildings. Consider the description for the effect of the ground layer (represented in the form of equivalent linear system) through an equivalent (effective) coefficient or transfer functions as completely valid. Such coefficients (or functions) should be taken as substantially dependent on amplitude of vibrations on bedrocks (arbitrary hardrock). In the simplest case, one can take only two versions of transfer functions (in terms of Eurocode-8): for small amplitudes and amplitudes of 0.3–0.4 g (SMZ, SNiP).

(8) Approve the need of choice of the general approach to taking the nonlinearity of ground behavior into account in the construction norms for mass building. The following approaches can be chosen: (a) abandoning of taking nonlinearity into account; (b) taking nonlinear effects into account "on average" for a certain range of acceleration values—approach used in Eurocode-8; (c) explicit account of nonlinear effects' dependence on amplitude—approach used in

the norms of the United States (seismic engineering, SNiP, SMZ).

(9) Abandon the principle of integer-valued intensity and ground categories; elaborate the more fractional classification of grounds and loads. The simplest solution: introduce half-unit intensity (i.e., with the 0.5 step: 6, 6.5, 7, 7.5 etc.) and five ground categories (1, 1.5, 2, 2.5, 3) (SNiP, GSZ).

(10) Emphasize the incorrectness of the update in the most important aspects of regulatory norms solely for SNiP, GSZ, and SMZ. Updating these norms on standard seismic loads should be implemented on the basis of a complex approach, and in terms of joint SNiP–GSZ and SNiP–SMZ groups of problems.

(11) Point out an urgent need to develop an instrumental network for continuous recording of strong ground motions in the territory of Russia; without this network, neither an accurate estimate of seismic loads from local earthquake data nor an appropriate use of data from non-Russian studies are possible.

CONCLUSIONS

Resulting from the comprehensive fundamental and applied studies on the improvement of methods and technologies for prediction of seismic hazard, the GSZ-97 maps (general seismic zoning of the territory of Russian Federation) have been updated; the concept of new generation GSZ-2012 maps have been developed; the problem of representing the ground acceleration in maps, in addition to the traditional intensity units, has been investigated. It has been noted that application of probabilistic analysis procedures for seismic hazard estimate in terms of ground acceleration, at poor knowledge of ground motions in the territory of Russia, cannot yield sufficiently valid results. Instead of this, the amplitude estimates on the basis of PASH recalculation expressed in fractional intensity units have been suggested. Additionally, it has been proposed to construct the GSZ maps in terms of peak ground accelerations for hardrock.

The updated version of GSZ-97 was named as GSZ-97*. Its new improvements and modifications are listed below:

(1) The studies on further unification of the earthquake catalog for the territory of Russia and adjacent regions of Northern Eurasia have been made; the catalog is supplemented for the period since ancient times until 2010.

(2) The seismic regime of the main seismoactive regions of Russia, required for numerical parameterization of seismogenerating structures (seismolineaments, domains, and potential sources of large earthquakes), has been investigated.

(3) The LDF-model of ESZ for GSZ-97 has been updated (on the basis of the updated earthquake catalog and previously unknown active faults found, certain modifications have been made).

(4) The GSZ-97* set of maps has been expanded. In accord with the new Urban Development Code of the Russian Federation and international recommendations, the maps of $T = 100$ and 2500 years have been included.

(5) The big set of digital vector maps (layers) with differentiated estimates of intensity (with model steps of 0.5 and 0.1 of intensity units for all the used recurrence periods of 100, 500, 1000, 2500, 5000, and 10000 years) have been constructed.

(6) For the purpose of a more detailed seismic mapping, all the calculations of seismic effects are made in the regular triangular mesh (15 km on a side), which is more convenient for a spherical surface than the rectangular mesh of 25 km on a side (used in the GSZ-97).

(7) The GSZ-97* maps of peak ground accelerations for all the used recurrence periods of 100, 500, 1000, 2500, 5000, and 10000 years have been constructed. The maps of peak ground accelerations are calculated both in terms of the MSK-64 scale and the project of the new ShIZ-2010 earthquake intensity scale.

(8) All the new data on the update of the GSZ-97* and on design of ESZ maps for seismic zoning of the new generation (GSZ-2012) have been included into the Integrated Information System "Seismic Safety of Russia" and are available on the Internet for practical application.

(9) The project of the Code of Rules for GSZ studies has been developed and the recommendations related to development of modern methods for model seismic loads setting in regulatory norms have been made.

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