International Journal of Applied Environmental Sciences
ISSN 0973-6077 Volume 12, Number 5 (2017), pp. 967-976

http://www.ripublication.com

Tectonophysical Justification of PES Zones of Priurgalsky Region for Seismic Microzoning

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Abstract

The relevance of the investigated problem is stipulated for the necessity for potential seismicity differentiated assessment of the individual parts of the crust within extended fault influence zones. The purpose of the article is to study the practical implementation of the PES methodology for seismic zones. Leading research approaches to this problem consist in the newest vertical movements fields analysis, crustal movements gradients map generation and testing of magnitude parameters dependence on crystalline basement age in the study area that allows generating a PES zones map allocating a region's seismic areas. As a result, the analysis was focused on crust vertical movements fields and crust gradients in Priurgalsky region. Crustal blocks joints areas stress distribution character as well as direction and speed of blocks shiftings relative to each other and the maximum magnitudes were determined. The data obtained was tested by alternative geological and geophysical methods with good reproducibility. The information contained in the article may be useful in clarifying seismicity sources and study area seismic hazard, detailed seismic zoning and seismic microzoning for facilities construction in Priurgalsky region.

Keywords: magnitudes forecast, maps of morphoisohypses and gradients of crust, seismic hazard, frequency and strength of earthquakes.

1. INTRODUCTION

The research area is traffic artery Taishet – Sovetskaya Gavan in Eastern Siberia and the Russian Far East, located in high seismic risk zone. Earthquakes of maximum strength are typical for Tynda – Khani region and decrease towards the south-east in Sikhote-Alin fold system (near Sovetskaya Gavan) [1, 2]. Priurgalsky region is characterized by high seismic hazard [3, 4, 5]. In the context of its future economic development the problem of the seismic zoning of its territory became relevant.

2 METHODOLOGICAL FRAMEWORK

Earthquake intensity evaluation methods

The authors used the latest vertical movements fields map, generated on the basis of analysis of apical surface of geomorfological profiles, hydrographic network planned image using remote and field observations data for magnitudes values forecast.

Areas with the highest shear stresses are confined to crustal blocks joint areas, shifting in different directions and at different speeds within the blocks themselves or relatively each other. These elements are characterized by high velocity gradients values of the latest and modern vertical tectonic movements. The elements of modern tectonics are well manifested in the mountainous terrain of Far-Eastern region [5, 6, 7, 8, 9]. High-altitude position of apical surface are corrected for denudation (with a positive sign) and residual relief (with a negative sign).

Denudation corrections are introduced based on the analysis of geomorphological profiles and reconstruction of slopes denuded parts and watershed surfaces according to erosive (ground and upland terraces and lobs, high-leveled down-cuttings) and denudation remnants (lobs and piedmont pediments of island mountains and peaks). The fact that apical surface in Far-Eastern region lowers due to oncoming recession of watershed slopes parallel to themselves is taken into account. The principles of the similarity of slopes can be witnessed during their reconstruction.

The analysis of the slopes, bottom, steeper, upper and flatter parts of which remain intact gives reliable data. According to researches, the both parts retain their closely parallel similarity in the process of slopes retreat [10, 11, 12].

This very fact is considered in the course of the graphic superstructure of watershed denuded part.

Comb-shaped watersheds are of little use for such reconstructions, since they served as a platform for almost complete meeting of opposite slopes. And in the course of their interpretation errors in both signs are possible.

This method is more reliable for mountain areas and gives the worst results for intradepression upheavals weakly expressed in relief, where it is difficult to reconstruct slopes and it is necessary to interpolate data on the magnitude of denudation, based on the structure of similar adjacent areas.

The amendment of the original residual relief (negative) provides for the existence of a volcanic mountain terrain, the altitude values of which amounts to up to 500 m in the areas of Mesozoic volcanism manifestations.

At the same time "coarsening" of its planned image by generalization, in order to avoid the loss of information about the lateral location of blocks relative to each other, as well as the location of splits dividing them, was not made. Rarely rather extensive neo-tectonic violations have the form of a compact fracture with large shiftings, and in most cases they form high-powered areas with total deformations for feathering and ramose private violations.

On the basis of the principles set out the analysis of vertical neo-tectonic deformation of crust with generation of morphoisohypses map which in its turn is source material for the latest and modern vertical tectonic movements velocity gradient map generation is conducted.

This indicator allows to identify areas with the greatest tangential tectonic stresses in the crust, since it reflects the maximum value of seismic tectonic processes intensity.

According to the statistical results, correlation between velocity gradients of the latest tectonic seismic movements (for 59 pairs of quantitative parameters values describing the relation and space variation of gradients and magnitudes) was revealed in extended Mongol-Okhotsk lineament, that is mapped in the border zone between Bureya mountain mass and Sikhote-Alin faulting. This lineament ends in the east in the form of an extensive system of deep breaks (Otunsky, Paukansky, Tastahsky and others) locating in the territory of the Far Eastern region [13, 14, 15, 16]:

$$\mathbf{M = 0,33 \left| grad\ V \right|_m + 5.2} \qquad (1.1)$$

where $\left| grad\ V \right|_m$ is measured in $\mathbf{n \cdot 10^{-9}}$ year $^{-1.}$ The correlation coefficient amounts to 0.6 ± 0.09 with a high degree of reliability.

According to these dependencies conclusions about seismic hazard level are made relying on gradients values. Earthquake magnitudes calculated for the region have good convergence with maximum values of the earthquakes magnitudes that have already occurred in this region.

The initial step to generate predictive magnitudes map is the newest vertical tectonic movements velocity gradients map. The authors generated a map of gradients for Priurgalsky region of the Trans-Amur Territory on a scale of 1to 200 000 by means of the well-known procedure [14], which was modified by V. V. Nikolaev [13, 17, 18, 19, 20, 21].

The map of total deformation of source (peneplenized) relief in isolines located 100 m apart from each other (morphoisohypses map), reflecting the region's tectonic development direction in neogene quaternary period (activation period is 25×10^{6} years) was accepted as a source material [22].

A sliding circular crossplot with the constant diameter of 16 km was used. The amount of isolines traversed by this diameter was mapped on a grid with a 10 km pitch, wherein adjacent sliding windows were overlaid by about 30%. Then isogrades lines were built.

The calculation of the gradients at each point (10×10 km^2 area) was made based on the formula (Nikolaev V. V., 2000)

$$\left| \mathbf{grad\ V} \right|_{m} = \mathbf{\Delta h \cdot (n-1) / d \cdot T} \; ; \qquad (1.2)$$

where d = 16000 m – crossplot diameter;

Δh = 100 m – isolines contour interval;

n - number of isolines, falling in crossplot;

T = 25×10^{6} years - the activation period under study.

For the conditions given:

$$\left| \mathbf{grad\ V} \right|_{m} = \mathbf{(n-1) \times 0{,}025 \times 10^{-8}} \qquad \mathbf{(year^{-1})} \qquad (1.3.)$$

Parameterization of PES zones

The earthquake magnitude calculated by this method can be referred to a certain maximum rate [14]. However, the initial values and the latest movements velocity gradients don't contain any physical or energy information in quantitative terms. They represent only one of the quantitative geological criteria of seismic activity. In our opinion, they need to be confirmed with the help of independent parameters, indirectly indicating the seismicity of the area and its geological structure.

The maximum possible earthquakes and their spatial localization and temporal repeatability are of great importance for practical purposes (seismic zoning and seismic microzoning) [23].

In the absence of other criteria, repeatability in a first approximation can be calculated with the help of simple models, such as Gutenberg-Richter cumulative graphics.

The situation with M_{max} definition seems to be somewhat more complicated. The maximum magnitude that can be generated by a particular PES, it is defined by geological structure, level of accumulated stress, slips, etc. With the help of seismic observations in a particular area it is difficult (or impossible) to determine M_{max} value due to the extreme rarity of the events close to the maximum possible ones. Therefore, in order to judge them, the indirect factors (seismological, geophysical and geodetic data) related to conditions in the areas of the incipience and occurrence of earthquakes are taken into account. Different correlated methods for M_{max} calculation, based on a relationship between M_{max} and other factors, are usually used in this approach; one of them is described in the previous section.

According to the reference [17], the energy level of earthquake depends essentially on the structure of crust and its strength properties ceteris paribus (homogeneous tectonic stress field, right-side oblique slip faults along slips, the same type of crust, etc.). That is, we can assume that the younger folded basement is, the greater is the likelihood of tectonic stress removal by means of relaxation properties of host rocks. The selection of the epicenters of strong earthquakes with their magnitude assessment and simultaneous foundation age dating in billions of years was conducted on the basis of this assumption. The data was plotted and regression equation took the following form

$$\mathbf{M = 9{,}9\ T + 2{,}58,} \qquad (2.\ 1)$$

where T - basement age, bln years.

Research area is located within Eastern Bureya block of Bureya mountain mass that is an integral part of the Amur geoblock.

3. RESULTS

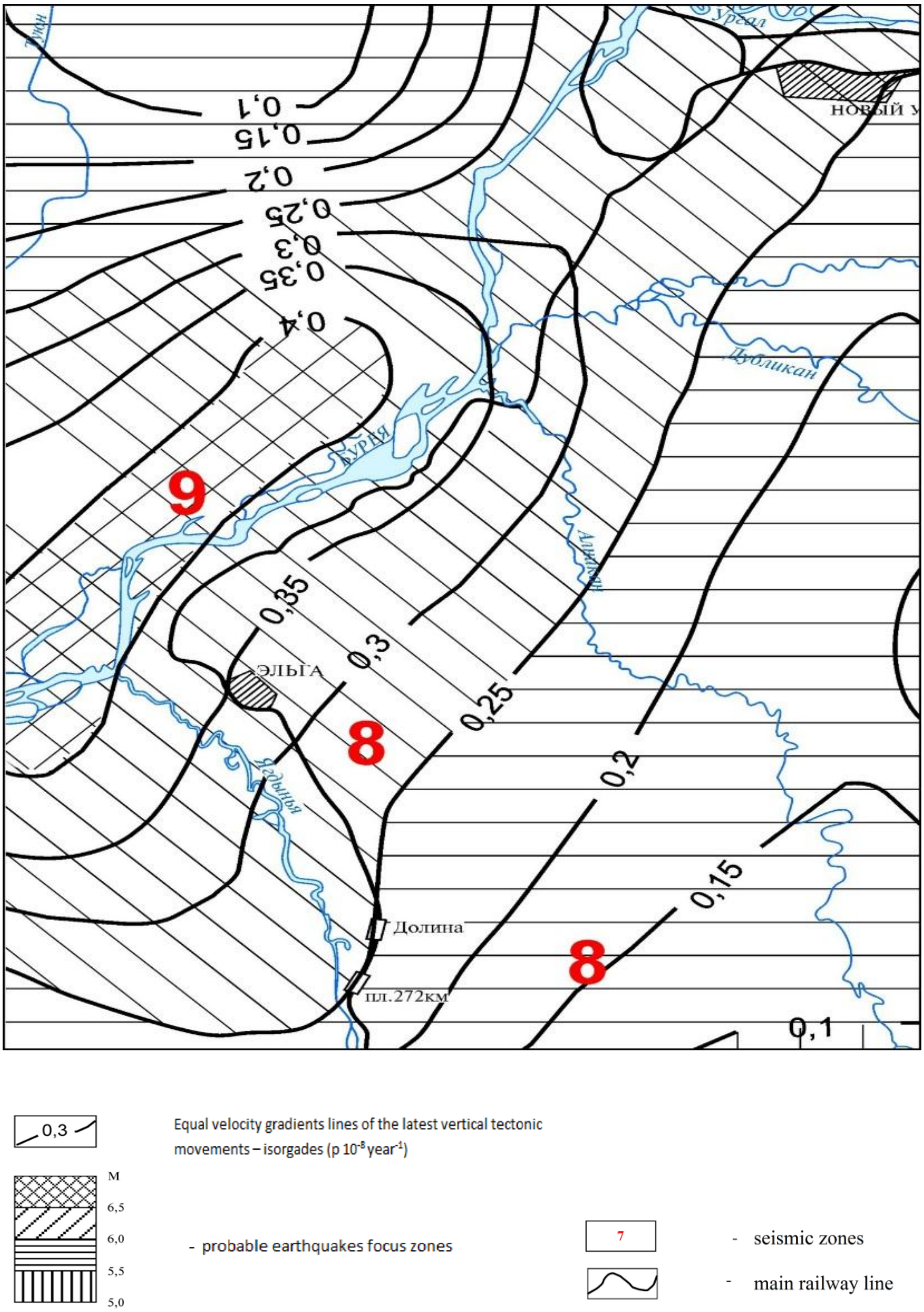

Fig. 1. Map of the latest vertical tectonic movements velocity gradients and PES zones of Priurgalsky region (fragment), scale 1: 200 000.

Maximum magnitude M_{max} of the events observed were taken in order to determine the frequency of their occurrence. The number of events for the magnitudes from M_{min} = 3.0 to M_{max} with ΔM_{LH} = 0.5 pitch was calculated in $M_{LH} - 0,25 < M_{LH} \leq M_{LH} + 0,25$ magnitudes intervals and referred to the center of the interval. The number of earthquakes was normalized per 1 year unit time in order to obtain comparable estimates of repeatability, considering the occurrence of earthquakes of different magnitudes. Only cumulative number N (M_{LH}) of earthquakes with $M \geq M_{LH}$ magnitude was determined.

The empiric recurrence schedule for Bureya area (cumulative) was approximated in $M_{min} \leq M \leq M_{max}$ magnitude interval by means of Gutenberg-Richter equation:

$$\lg N(M) = a + b M, \text{ earthquakes / year} \quad (2.2)$$

where N (M) is a cumulative number of events with a magnitude equal to or exceeding M; a and b - recurrence schedules coefficients determined by least squares technique

Table 1. Earthquake recurrence schedule for the research area

Zone	Area, ths. km ^{2}	Magnitudes range	$a \pm \delta\alpha$	$b \pm \delta в$	σ(lg N)	R
1	2	3	4	5	6	7
Bureya	748.125	3.0- 7.0	-0 .74 ± 0.2	-0.22 ± 0.04	0.132	-0,912

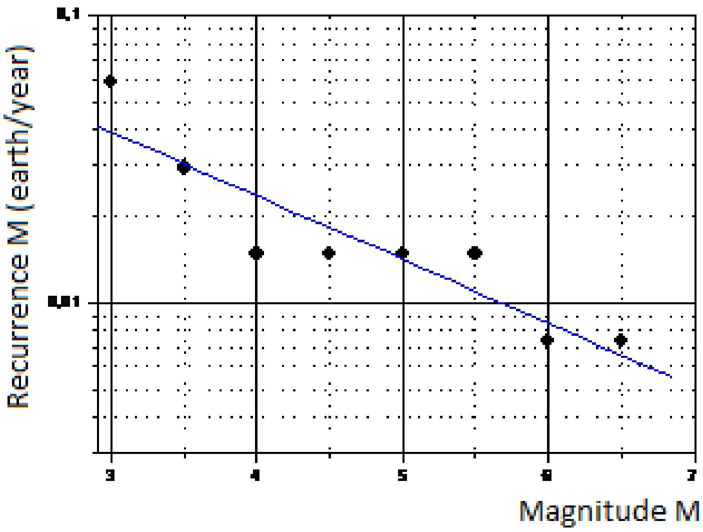

Fig.2 - Schedule of earthquake recurrence for Bureya PES zone

Magnitude Intervals in the calculation of initial seismicity are set based on the following conditions. Minimum magnitude is taken as the lower limit of M_{min}, it contributes to seismic hazard assessment. The upper limit M_{max} is determined by the "opportunities" of the specific PES area. Within the framework of this model with The value of 4.0 is accepted as the value of M_{min}. At a first approximation, with an average depth of focus h = 15 km, surface seismic effect in the epicentral area will amount to I_{msk}=4.9 points for the subsoils of category II SR 14.13330.2014. In construction practice seismic conditions with I_{msk}≥6.0 points are taken into account. In view of the possible deterioration of subsoil seismic properties to category III and, as a consequence, possible increase in intensity by 1 point, the assumed value of M_{min}=4,0 seems to be quite reasonable.

In further calculations of SHL, PES zones are classified by specified magnitudes interval with 0.5 pitch. At the same time, earthquakes with M = 4.0 (± 0.2), M = 4.5 (± 0.2) and M = 5.0 (± 0.2) are associated with areal zones and earthquakes with M ≥ 5.5 (± 0.2) will be confined to the lineaments.

4. DISCUSSION

Taking into consideration the lack of seismostatistics for continental Russia's Far East, which, in general, is characterized by a moderate seismicity, similar analysis using existing tectonophysical, seismogeological and seismological information can make a significant contribution to the resolution of the uncertainties associated with seismic process quantitative parameters definition. Indeed, modern building codes of the Russian Federation require for the initial (background) seismicity identification prior to local seismic microzoning when building major facilities. In view of the fact that Russia is vast, the federal building codes contain maps and lists of settlements, reflecting the very small, so-called Federal scale of seismic process but it is practically impossible to take into account all the factors affecting the final seismic hazard assessment [24].

As it turned out in the course of the research, the application of two independent quantitative methods of magnitudes forecast by tectonic data on the one hand [25] and geological data on the other [10] to a relatively small local area of Priurgalsky region yielded positive results in solving the uncertainties listed above –energy level and future earthquakes time intervals justification for justified PES model development.

6. CONCLUSION

Areas with the highest shear stresses are confined to crustal blocks joint areas, shifting in different directions and at different speeds within the blocks themselves or relatively each other. These elements are characterized by high velocity gradients values of the latest and modern vertical tectonic movements.

The latest vertical movements and crustal movements gradients fields analysis allowed to generate a PES map of Priurgalsky region. Magnitudes of probable seismic event amount to 5.0 – 6.5.

The dependence of magnitudes parameters on crystalline basement age was detected on the basis of strong earthquakes epicenters selection with the assessment of their magnitudes and simultaneous dating of foundation age in billions of years. Estimated interval of magnitudes, received at SHL calculation for the seismotectonic model adopted amounts to 4.0-7.0.

The proposed methods allow for seismic microzoning of large extended objects.

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