4.3.1. SEISMICITY OF BULGARIA

Ludmil Christoskov, Dimcho Solakov, Stella Simeonova

4.3.1.1. General considerations

Bulgaria is situated in the eastern part of the Balkan Peninsula. The Balkan Peninsula, from a plate-tectonic point of view, is an element of the continental margin of Eurasia. This margin is located between the stable part of the European continent (the Moesian platform) to the north and ophiolitic sutures (Vardar and Izmir-Ankara) to the south. South of the sature, fragments of the passive continental margin of Africa crop out (Boyanov et al., 1989).

The eastern part of the Balkan region comprises variable in type structural units differing in age, origin, tectonic style and contemporary geodynamics. The Moesian Platform (an area of a stable tectonic development) borders to the North, west and south on the Alpine orogen that is represented by the folded Carpathian and Balkanides systems. During the Alpine stage this area was a mobile tectonic zone filled up with numerous linear units of a block-fold structure. The latter units were orderly accreted to the Moesian Platform margins over the process of their development. The Carpathian-Balkanide orogen tectonic units are positioned in the southwestern "active" paleo-margin of Eurasia - at the Moesian Platform flanks, respectively. The other units of the Alpine zone on the Balkan Peninsula - Dinarides-Helenides-Taurides, are related to the "inactive" paleo-margin area of Africa. The region also covers Upper Cretaceous volcanogenic-sedimentary belt of the Tymok-Srednogorie zone, the belt of the metamorphic Rhodopes, Serbian-Macedonian and Apuseny massifs, the collage units of the Pre-Rhodopean, East Rhodopean and Sakar-Strandja zones. Over the Late Alpine post-collision development stage a series of Paleogene-Neogene graben systems and basins were formed. The neotectonic phase within the region comprises tectonic processes that took place during the Neogene and Quaternary (the last 12-14 Ma). This stage is considered as the latest concluding phase of the Late Alpine tectonic cycle (approximately 45-50 Ma) which demonstrates specific phenomena in the Balkan part of the Alpine orogenic system - formation of molasse sedimentary complexes of the early orogenic (Late and Early Paleogene) and late orogenic (Neogene-Quaternary) periods. The Balkan part of the Alpine orogenic system represents a mixed mosaic of neotectonic structures (morphostructures) of variable activity during the neotectonic stage. The characteristics and distribution of the neotectonic processes are marked by direct configuration differentiation, related to the initial pre-neotectonic structural-geological individuality of the territory. In individual morphostructures, these processes retain the basic trends of their Alpine evolution, i.e. the neotectonics is influenced by the previous Alpine regional evolution related to the complicated development and relations of the stable Euro-Asian plate (East European Platform, including the Moesian Platform) with the Africa plate. This relation is demonstrated by the collision effects - formation of range-dome mountain elevations and subsidences in the suture zones between the platform and the orogenic structures. Substantial inner transformations of the

geostructures established by geological and geomorphological data were realized during the neotectonic period due to specific vertical and horizontal tectonic stresses (Dachev et al., 1992).

The data on the Earth crust and upper mantle structure in Bulgaria are not sufficiently detailed. From the seismic, gravimetric and seismological investigations it is established the crust thickness varies between 30 km and 50 km. The crust in the region of Rila mountain is the thickest (50 km), of Pirin (45-50 km), of the Rhodopes (40-45 km) and the it is thinnest in the Moesian platform (30-35 km) in N Bulgaria.

4.3.1.2. Seismic activity

The earthquake activity in Bulgaria is the most apparent manifestation of contemporary geodynamics on its territory (Boncev et al., 1982). Over the past centuries, Bulgaria has experienced strong earthquakes. Some of the Europe′s strongest earthquakes 20-th century occurred in Bulgaria (at the beginning of the 20-th century from 1901 to 1928 on the territory of Bulgaria occurred 5 earthquakes with magnitude larger than or equal to 7.0). The strongest and most destructive earthquakes in Bulgarian occurred after 1900 are given in Table 4.3.1.1.

Table 4.3.1.1. Strong and destructive earthquakes in Bulgaria after 1900 year

Date d. m. y.	Time GMT h. m. s.	Epicenter coordinates φ°N	λ°E	h km	M	E in J	I_0
31.03.1901	07 10 22	43.37	28.70	14	7.2	$2.7\ 10^{15}$	10
04 04 1904	10 02 34	41.77	23.05	15	7.3	$3.8\ 10^{15}$	9-10
04 04 1904	10 25 55	41.85	23.08	18	7.8	$1.9\ 10^{16}$	10
08 10 1905	07 27 30	41.86	23.08	19	6.4	$1.8\ 10^{14}$	8-9
15 02 1909	09 33 40	42.52	26.48	4-8	6.0	$4.3\ 10^{13}$	8
23 02 1910	07 52 14	41.70	23.55	10	5.4	$4.7\ 10^{12}$	7-8
14 06 1913	09 33 13	43.10	25.70	15	7.0	$1.4\ 10^{15}$	9-10
18 10 1917	18 57 40	42.70	23.33	6	5.2	$2.2\ 10^{12}$	7-8
14 04 1928	09 00 01	42.21	25.36	10	6.8	$7.1\ 10^{14}$	9
18 04 1928	19 22 48	42.20	25.06	16	7.1	$2.7\ 10^{15}$	9-10
25 04 1928	09 25 46	42.08	25.89	13	5.7	$1.4\ 10^{13}$	8
23 08 1942	15 41 25	43.47	26.60	10	5.1	$1.5\ 10^{12}$	7
30 06 1956	01 50 22	43.55	28.68	20	5.5	$6.8\ 10^{12}$	7
03 11 1977	02 22 58	42.08	24.08	8	5.3	$3.2\ 10^{12}$	7
21 02 1986	05 39 56	43.21	26.01	8	5.1	$1.5\ 10^{12}$	7-8
07 12 1986	14 17 09	43.19	26.01	10	5.7	$1.4\ 10^{13}$	8

Notes: the magnitude M is determined by surface waves; the energy E is calculated by the relation $\log E=2.23+2.23M-0.055M^2$: the epicentral intensity I_0 is given in grades of macroseismic scale MSK-64;

The spatial pattern of seismicity in Bulgaria and adjacent areas is shown in Fig. 4.3.1.1. The figure represents the epicentral map of the earthquakes with M≥4.0. This map shows that seismicity is not uniformly distributed. Therefore the seismicity is described in distributed geographical zones. From the seismotectonic analysis of the central Balkans this seems more appropriate than specific fault linear structures or three-

dimensional fault plane. The seismicity of Bulgaria is related to seismic zones defined on the base of spatial distribution of seismicity and the expected source zones as suggested by Boncev et al. (1982). The main seismic zones in Bulgaria are: Kresna, Sofia, Gorna Orjahovica, Shabla and Maritsa. Its own specific tectonic, seismic, and geological particulars characterize each zone.

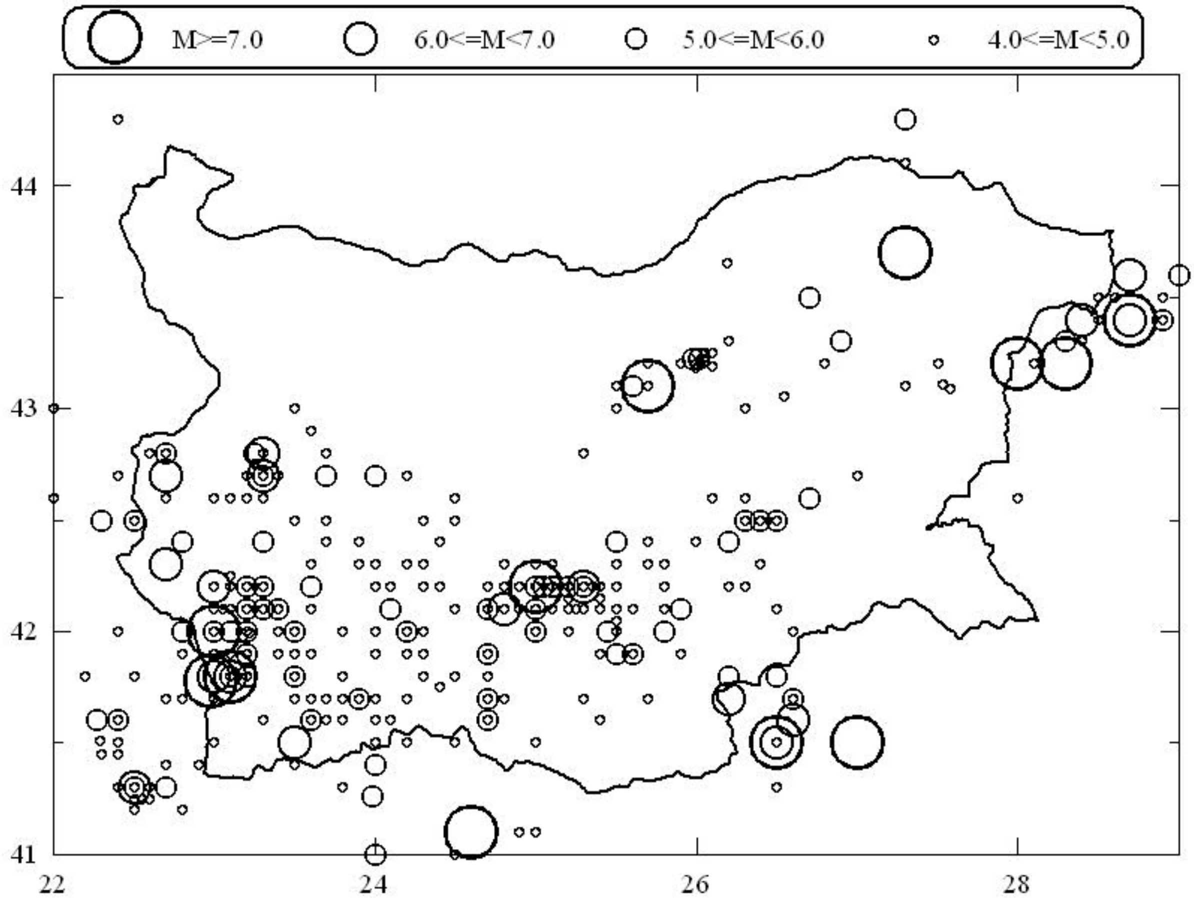

Fig. 4.3.1.1. Seismicity in Bulgaria and adjacent areas (M≥4.0)

The first documented earthquake on the territory of Bulgaria is the 1 c BC quake occurred in the Black Sea near the town of Kavarna.

In historical aspect it is worth mention the 1818 (VIII-IX MSK) and the 1858 (M≈6.5, I_0=IX MSK) earthquakes occurred near the town of Sofia. The 1858 earthquake caused heavy destruction to the city of Sofia and the appearance of thermal springs in the western part of the town. This mineral spring in the center of the town ran dry for 2 or 3 days, then issued again with higher temperature. The felt aftershocks continued more than 108 days.

Impressive seismic activity developed in the SW Bulgaria (in Kresna zone) during 1904-1906. The seismic sequence started on 4 of April 1904 with two catastrophic earthquakes within 23 minutes (the first quake at 10h 05m with M=7.1 considered as a foreshock and the second one at 10h 26m with M=7.8 and I_0=X-the main shock). The main shock was felt up to Budapest (Hungary) and some eyewitnesses have seen waves on the surface in the town of Sofia. The surface outcrop caused by the 1904 earthquake still can be seen in the Kresna gorge. This earthquake was followed by a well-expressed long-lasting aftershock activity.

In the Northeast Bulgaria two strong earthquakes occurred. The first one is of 31 March 1901 near the town of Shabla with epicenter in the Black Sea, and the second one is the 1913 earthquake in the Gorna Oryahovitsa zone. The latter quake destroyed the towns Veliko Tarnovo and Gorna Oryahovitsa and a lot of villages in the region. In historical aspect the 358 AD earthquake in the Black Sea should be noted. A tsunami wave (of about 4-m) was formed in the Varna bay.

Along the Maritsa valley (central part of Bulgaria), in 1928 a sequence of three destructive earthquakes occurred. The towns Plovdiv, Chirpan, Parvomay suffered great damage. Many other towns and villages were strongly affected. 74000 buildings were completely destroyed and 114 people killed. They caused two surface coseismic ruptures, each of them several tens of kilometers in length. This is the one of few cases (quoted in world literature) when before and after a strong earthquake detailed geodetic surveys have been performed. On some places the ground displacement reaches 1.5-2 m. However, no such large earthquakes occurred in Bulgaria since 1928. The 1986 earthquake (with magnitude 5.7) that occurred in the central northern Bulgaria (near the town of Strazhitza) is the strongest quake after 1928.

From the analysis of the depth distribution it was recognized that the earthquakes in Bulgaria occurred in the Earth's crust up to 45 km. The hypocenters are mainly located in the upper crust, and only a few events are related to the lower crust. The maximum density of seismicity involves the layer between 5 and 25 km.

The fault plane solutions of some recent earthquakes suggest predominantly normal and reversed faulting in the region. The compression and tension axes inferred from the focal mechanisms are in NE-SW and NNW-SSE directions respectively and are consistent with the general stress pattern of the Balkan region.

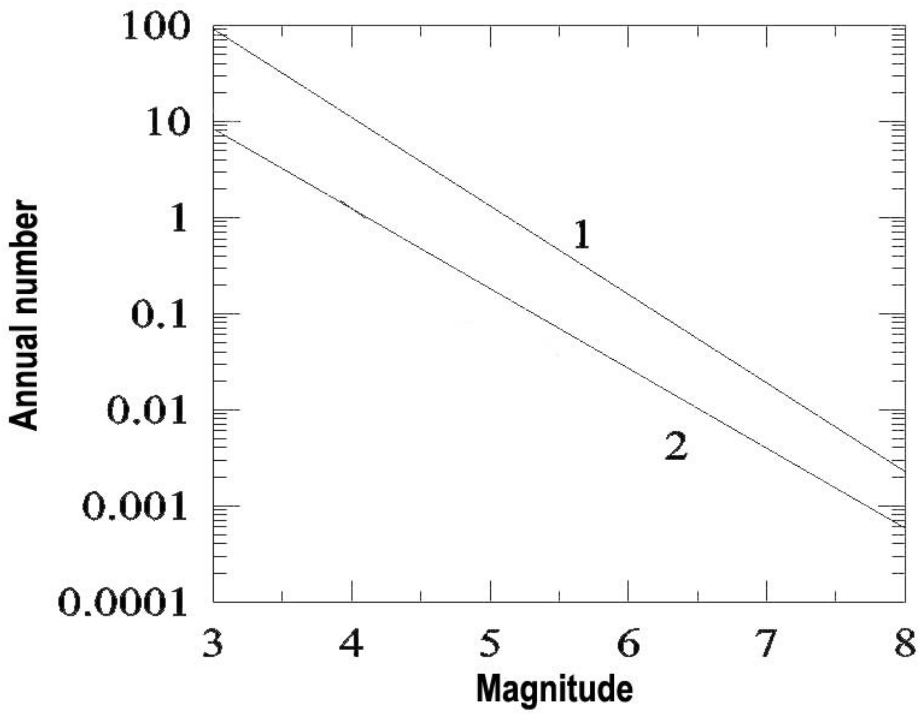

Fig. 4.3.1.2. Earthquake recurrence, 1 – Central Balkans, 2 – Bulgaria

The earthquake recurrence in Bulgaria is presented in Fig. 4.3.1.2. and the values for the mean annual number of the earthquakes N and the mean interval between them T=1/N according to equation logN=a-bM are given in Table 4.3.1.3. For comparison the assessments for the Central Balkans are shown, including the neighboring zones from which unfavorable consequences for Bulgaria can be expected. It is immediately understood that the number N for Bulgarian earthquakes is lower more than ten times for M≤4, but for M≥7 this ratio decreases to 4-5 times. The latter means the impact of the strong Bulgarian earthquakes is significant.

Table 4.3.1.2. Earthquake recurrence of Bulgaria and the Central Balkans

Magnitude	**Mean annul number of earthquakes N**		**Mean time period in years T=1/N**	
M	**Bulgaria**	**Centr. Balkans**	**Bulgaria**	**Centr. Balkans**
3	**8.3**	**91**	**0.12**	**0.01**
4	**1.23**	**11**	**0.81**	**0.09**
5	**0.18**	**1.32**	**5.5**	**0.76**
6	**0.26**	**0.16**	**37**	**6.3**
7	**0.004**	**0.02**	**250**	**52**
8	**0.0006**	**0.0023**	**1700**	**440**

Table 4.3.1.3 Number of earthquakes in the Balkan countries with M≥7 (1901-1970)

Country	**Number according to the national catalogues ***		**Number according to the Balkan catalogue UNESCO/1974**
	M≥7	**I_0≥9**	**M≥7**
Albania	**-**	**6**	**-**
Bulgaria	**6**	**6**	**5**
Greece	**16**	**73**	**11**
Romania	**11**	**4**	**1**
Turkey **	**13**	**21**	**5**
Yugoslavia	**2**	**18**	**-**

*** including some border earthquakes and/or duplicated events**

**** for the territory to the West of meridian 30°E**

It should be noted the earthquake activity in Bulgaria is lower than that of the neighbor countries, before all of Greece and Turkey – both in the number of strong earthquakes and also of their recurrence (Table 4.3.1.2. and Table 4.3.1.3.).

4.3.1.3. Seismic zoning

Initially the so-called statistical variant of seismic zoning of Bulgaria has appeared. The map of the maximal observed intensity I_{imax} have played the role of seismic zoning map and reflects the realized to the moment earthquake activity. The statistical variant does not offer any evaluation of the locations of earthquake source zones neither the recurrence period of the impacts with a definite intensity.

In the prognostic variants of the seismic zoning (see Medvedev (ed.), 1968, Riznichenko, 1976, 1985, Shebalin et al., 1976, Algermissen et al., 1976, Bune, Goroshkov (ed.), 1980, Boncev et al., 1982), the above shortcomings are gradually removed. The final result are

a map of the possible source zones (PSZ) of future earthquakes and shakability maps of different recurrence periods.

The prognostic zoning is based on the following most important principles:

(1) the zoning final products must be of a prognostic type unlike the statistical approach;
(2) in correspondence with the available information to minimize the groundless increase of the seismic danger, but at the same time no omissions are admissible for potentially dangerous zones;
(3) all available seismological, geological-tectonic and geophysical data for the territory under investigation to be used; when necessary these data to be supplemented by new investigations, so that a necessary optimum of input information to be reached;
(4) the zoning territory has to cover all adjacent earthquake zones, which can produce unfavorable impacts; the territory itself is split in seismic regions and zones, endeavoring to reach representatives of the most important statistical data (recurrence, macroseismic models, etc.);
(5) under condition of block constitution of the geotectonic structures in earthquake territories, it is assumed the seismic generation process is principally related with the conjunction zones between the different blocks and structures, along whose boundaries and intersection points (lineaments and lineament knots) the relative movements and displacements are most probably to be realized;
(6) physically argumented and formalized by rank and weights criteria (seismological, geotectonic, geophysical and complex) for the basic seismogenetic structures in the investigated territory are introduced; these criteria must have orientating role for evaluating the analogous in properties structures, which are not activated up to the moment, or about which there are no direct proofs for past earthquake activation;
(7) the methods of the seismo-tectonic analogies and of the expert evaluations (from about ten experts) are used in the elaboration of the criteria, taking into account the most important seismological assessments concerning the dimensions, depths of activation, recurrence and other parameters of the earthquakes with different energy;
(8) the seismological, geotectonic and geophysical investigations are carried out in parallel and independently; at certain stages a number of cases of intermediate complex products are realized; the final products are a result of the complex evaluation of earthquake danger by seismological, geotectonic (geodetic inclusive) and geophysical data;
(9) the complex investigations are realized in two stages: the first stage includes defining the potential seismic source zones (SSZ} within the magnitude interval 4.1-8.5, and the second one – determining the shakability for selected periods of quake recurrence with intensity I=7, I=8 and I≥9 grade, most often for 100, 1000 and 10000 years.

An impartial evaluation of the seismic danger for the territory of the country can be obtained from the prognostic seismic zoning maps. An idea of the location and the size of the expected earthquakes is given in the complex map of the possible source zones (PSZ, in Fig. 4.3.1.3.). The source zones are for the following magnitude intervals: 7.6-8.0, 7.1-7.5, 6.6-7.0, 6.1-6.5, 5.6-6.0, 5.1-5.5, 4.6-5.0, 4.1-4.5 and a background field with M≤4.0. The most dangerous PSZ are in SW and NE Bulgaria with magnitude up to 8.0. Very strong earthquakes can be realized in the Maritsa seismic zone, sources of strong earthquakes are connected with the Sofia and Gorna Oryahovitsa zones.

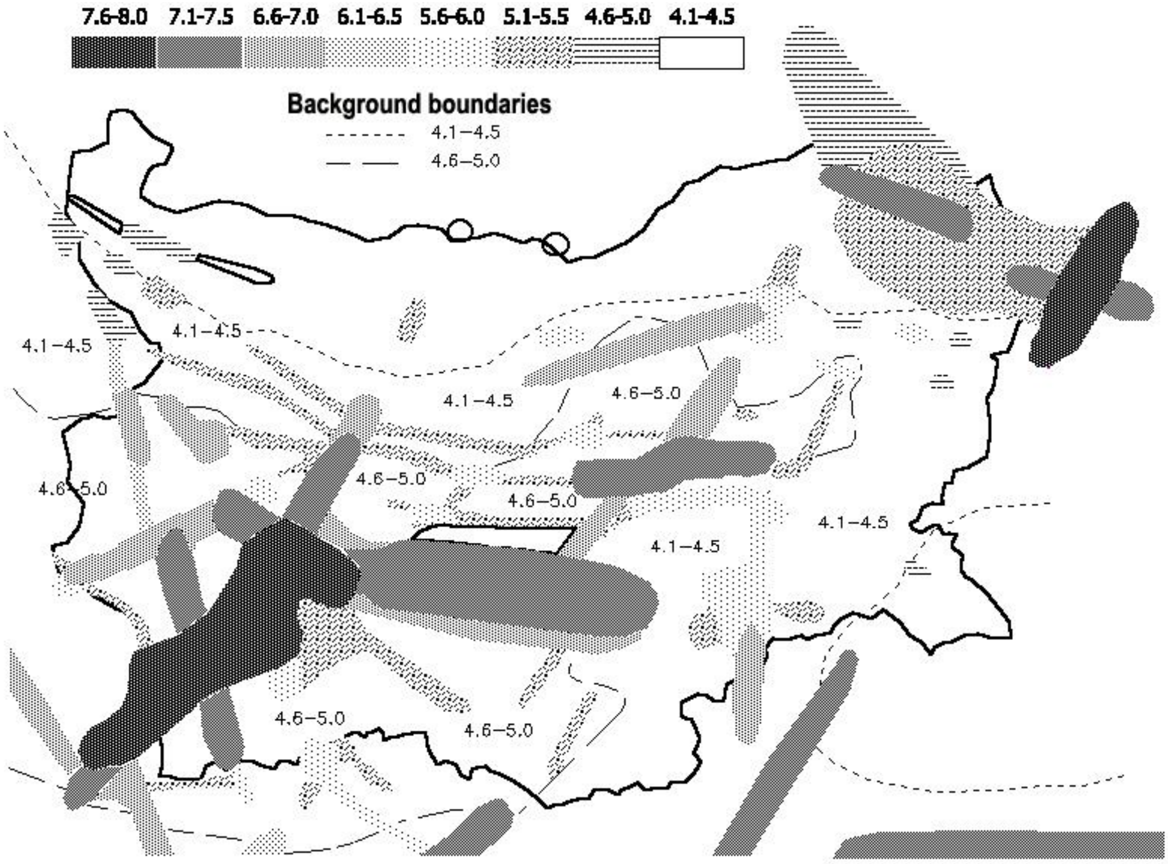

Fig. 4.3.1.1. Complex map of the possible source zones

An immediate idea about the strength of the possible impacts on the earth surface (the macroseismic intensity) and about the probable period of their realization could not be obtained from the PSZ map. The latter serves as a basis for evaluation of the shakability maps, i.e. maps of the expected intensity for the different time periods, for example for 100, 1000 and 10000 years. Such hazard maps can be drawn taking into account the earthquake recurrence and the macroseismic models of the average impact areas for intensity higher than or equal to 6. The hazard map for a 1000-year return period (in terms of MSK-64 intensities) is presented in Fig. 4.3.1.4. The adopted Bulgarian building construction code is based on this hazard map.

The intensity field on the 100 year map is the most dangerous from the viewpoint of short recurrence time, but the maximum expected intensities are of 7 grade (MSK). On the 1000 year map areas of strong impacts of intensity 8 and higher appear. In Table 4.3.1.4. the distribution of the areas with different intensity (in % of the territory of Bulgaria) for different shakability maps is given.

Table 4.3.1.4. Distribution of the areas of different intensity in % of the territory of Bulgaria

Seismic intensity (MSK)	6	7	8	≥9	≥7
Type of the map	Areas in % of the territory of Bulgaria				
Shakability 100 yr.	35	65	0	0	65
Shakability 1000 г.	2	51	28	19	98
Shakability 10000 yr.	0	22	44	34	100
Seismic code of 1961 yr.	75*	17	4	1	22
Maximal observed intensities I_{max}	36	49	11	4	64

***for 6 or lower intensity**

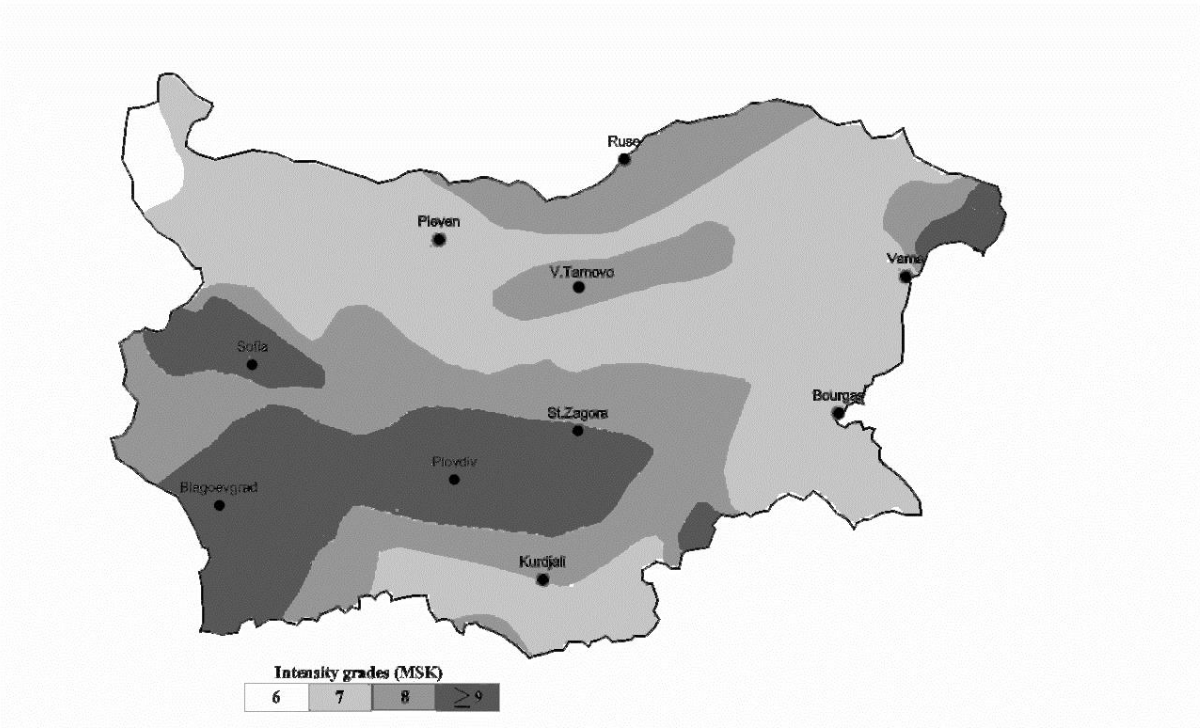

Fig. 4.3.1.2. Hazard map for a 1000-year return period (in terms of MSK-64 intensities)

4.3.1.4. Conclusion

In conclusion, the territory of Bulgaria represents a typical example of high seismic risk area in the eastern part of the Balkan Peninsula. It becomes clear from Fig. 4.3.1.4 and Table 4.3.1.4 that the larger part of the territory falls in intensity higher than or equal to 7 (98% on the normative map).

4.3.1.5. References

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