Seismic Hazard Modeling for Bulgaria

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Earthquakes are the most deadly natural disasters affecting the human environment; indeed catastrophic earthquakes have marked a large part of human history. Global seismic hazard and vulnerability to earthquakes are steadily increasing as a result of uncontrolled growth of mega cities in highly seismic areas around the world. It is often associated with the construction of seismically unsafe buildings and infrastructures and caused by insufficient knowledge of the regional seismicity peculiarities and seismic hazard. Over the centuries, Bulgaria has experienced strong earthquakes. The strongest events reached magnitude 7.8 in southwestern Bulgaria, magnitude 7.5 in northeastern Bulgaria, and magnitude 7.0 in southern Bulgaria. Moreover, the seismicity of the neighboring countries, like Greece, Turkey, former Yugoslavia and Romania (especially Vrancea-Romania intermediate earthquakes involving the non-crustal lithosphere), influences the seismic hazard in Bulgaria. Fig. 1 illustrates the spatial pattern of seismicity in and near Bulgaria.

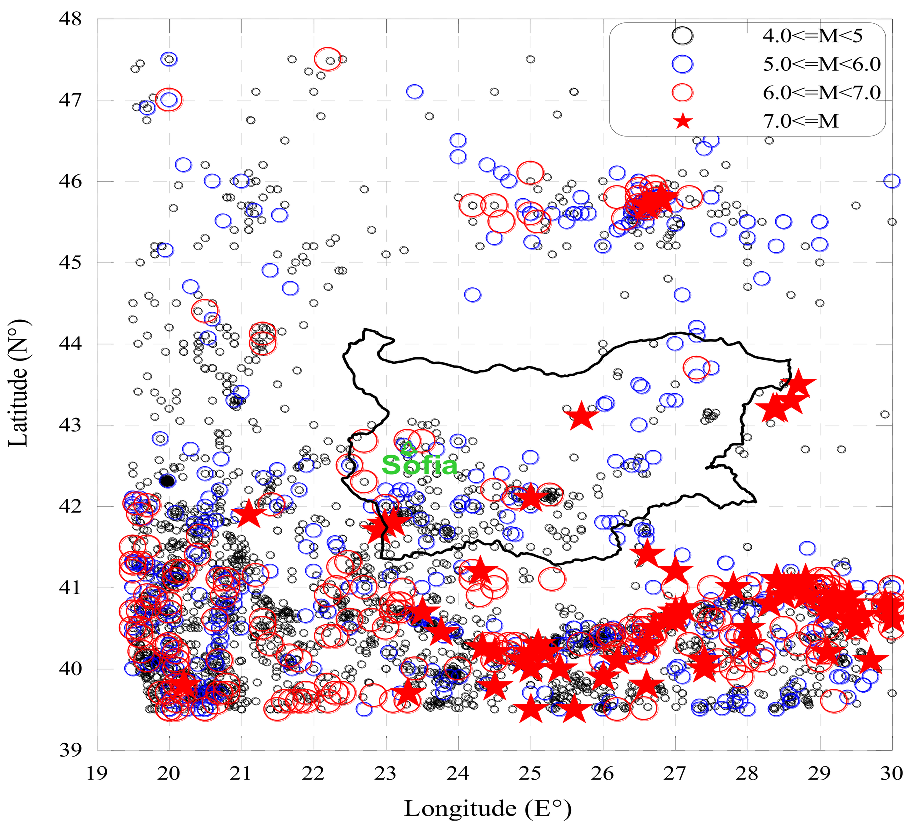


Fig. 1. Seismicity in and near Bulgaria with M≥4.0 (historical and instrumental)

Seismic hazard is the probability that various levels of strong ground motion will be exceeded during a specified time period at a site. The ground motion levels may be expressed in terms of peak ground acceleration (velocity, displacement) and/or peak response spectral amplitudes for a range of frequencies. The analysis is often summarized with a seismic hazard curve, which shows annual probability of exceedance (or frequency of exceedance) versus ground motion amplitude. A flow chart for main stages in probabilistic seismic hazard analysis is presented in Fig. 2.

Seismic hazard maps proposed as part of a new building code for Bulgaria based on the recommendations in EUROCODE 8 are generated applying probabilistic method (presented in Solakov et. al., 2009). The basic approach used for the creation of ground motion maps combines via GIS, source-geometry, earthquake occurrence model, the strength of the earthquake sources, and the appropriate attenuation relations. The PSHA was performed, using the Bulgarian version of computer code EQRISK.

As recommended in EC8, the maps are calculated for a 475 years return period (probability of exceedance of 10% in 50 years, presented in Fig. 3) for the design earthquake and for 95 years return period (probability of exceedance of 10% in 10 years, presented in Fig. 4) for weaker earthquakes with higher frequency of occurrence.

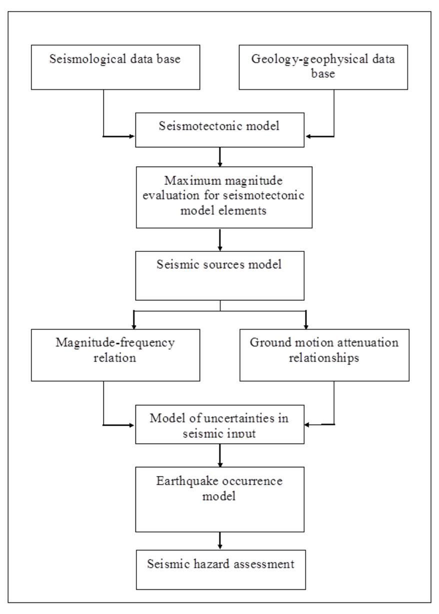


Fig. 2. Flow chart for seismic hazard assessment

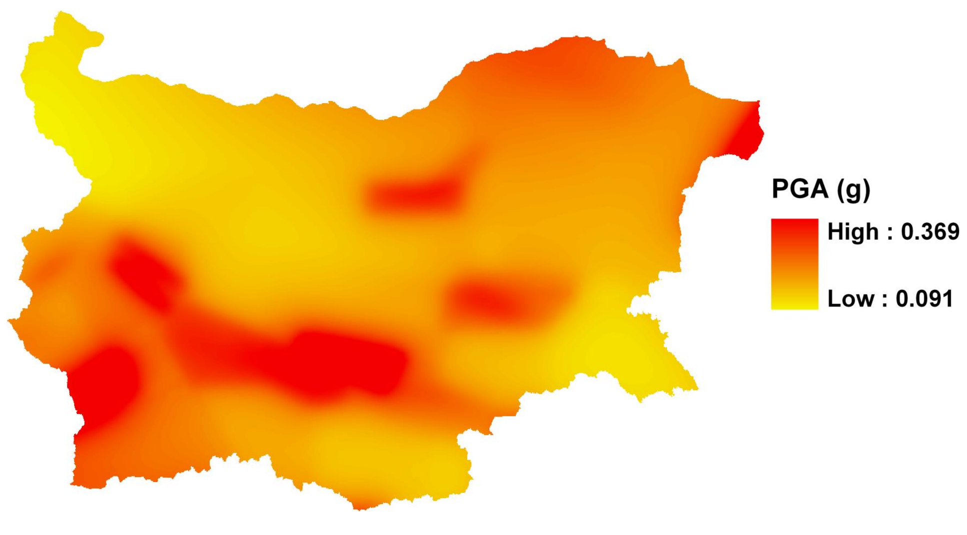


Fig. 3. Seismic hazard for Bulgaria in PGA for a recurrence period of 475 years; column represent PGA values in g

Fig. 4. Seismic hazard for Bulgaria in PGA for a recurrence period of 95 years; column represent PGA values in g

Seismic hazard disaggregation

A procedure called disaggregation has been applied to examine the spatial and magnitude dependence of PSHA results. The aim is to determine the magnitudes and distances that contribute to the calculated exceedance frequencies at a given return period and at a structural period of engineering interest. The hazard for 27 cities on the territory of Bulgaria for a 475 years return period and at PGA is partitioned into selected magnitude and distance bins (Solakov et al., 2012).

PSHA disaggregation shows the following results:

1) Unimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA is observed. The mode of the distribution is for magnitude 5.0-7.5 earthquake at a distance of 5 to 20 km from the city. The strongest contributor to the hazard is the near regional seismicity – Fig. 5 a) and Fig. 5 b);

2) Unimodal distribution of earthquake magnitude and distance to intensity exceedance frequency - the strongest contributor to the hazard for the cities of Ruse and Vidin, Vraca, Montana, Razgrad, Pleven is the Vrancea intermediate source – Fig. 5 c);

3) Bimodal distribution of earthquake magnitude and distance to intensity exceedance frequency - the hazard for the city of Dobrich is influenced both from near region seismicity and Vrancea intermediate earthquakes. The strongest contributor to the hazard for recurrence period of 475 years is the near regional seismicity – Fig. 5 d);

4) Unimodal distribution of earthquake magnitude and distance to intensity exceedance frequency - the strongest contributor to the hazard for the city of Veliko Turnovo is the near regional seismicity – Fig. 5 e).

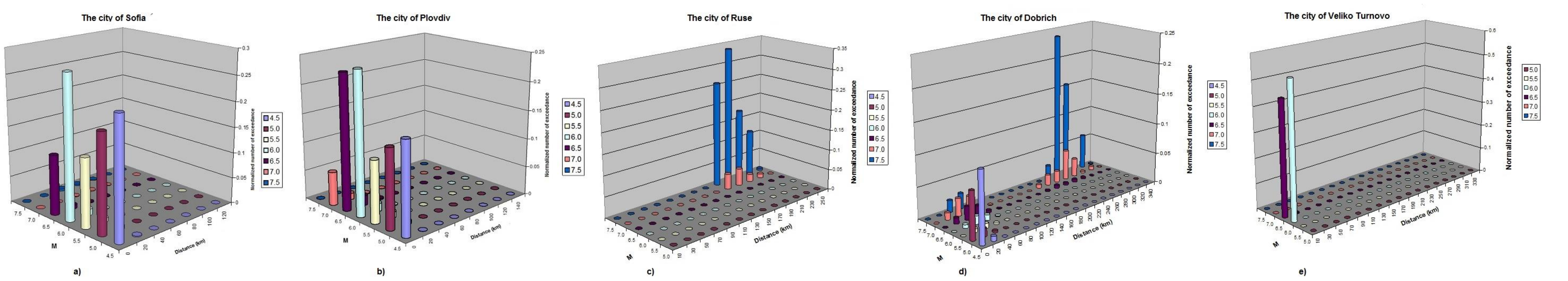


Fig. 5. PSHA disaggregation showing the distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA

Additionally, hazard maps in intensity scale for Romania-Bulgaria cross-border region were generate in the DACEA project that, was implemented in the framework of the Romania - Bulgaria Cross Border Cooperation Programme (2007-2013). The seismic hazard for Romania-Bulgaria cross-border region is assessed on the basis of integrated basic geo-datasets. The hazard results are obtained by applying two alternative approaches – probabilistic and deterministic (presented in Solakov et al., 2014).

The calculated probabilistic hazard (illustrated in Fig. 6) indicates that the MSK64 intensity VII will be exceeded with probability 0.1 within 50 years (return period 475 years) for the large part of the Romania-Bulgaria cross border region. The map for 475 years return period displays the highest intensity values (about VIII MSK64) for the southern part of Romania (the effect of the Vrancea intermediate depth earthquakes). And also in the south-easternmost part of the target region, at the Black sea costal area (the seismic source in Black sea). The intermediate depth earthquakes of the Vrancea source dominate the hazard in the central northern part of the Romania-Bulgaria cross border region. Fig. 7 shows the seismic hazard map generated using the deterministic approach. A significant increment (about 1 intensity degree) of the deterministic hazard values, compared to those estimated in the probabilistic approach is observed in the vicinity of the shallow sources in northern Bulgaria (southeastern part of the analysed zone) – Gorna Oryahovitsa (GO), Dulovo, and Shabla (SHB).

Fig. 6. Seismic hazard map for Romania-Bulgaria cross-border region (475 years return period); colors represent the intensities in MSK64 scale

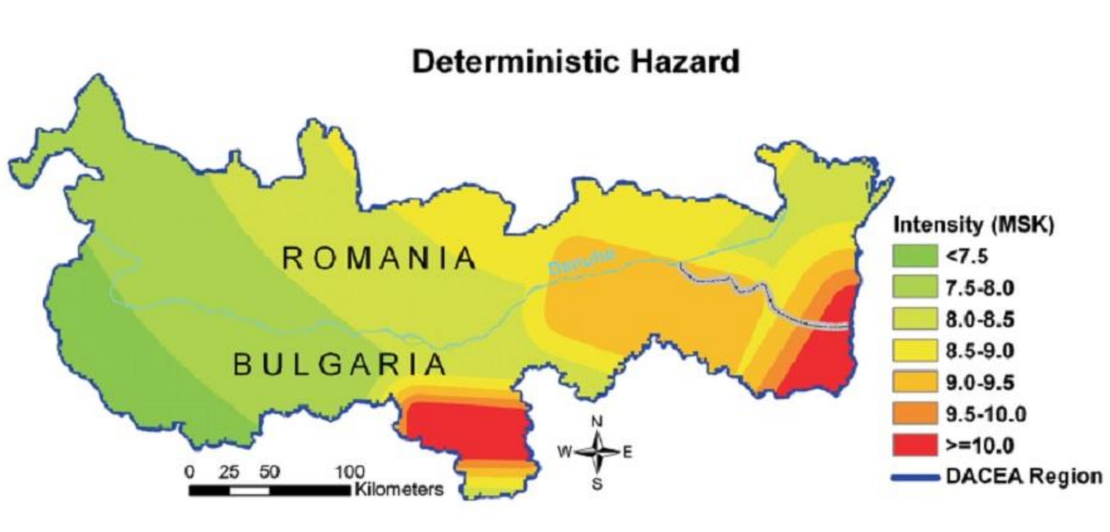


Fig. 7. Seismic hazard map generated using a deterministic approach; colors represent the intensities in MSK64 scale

Earthquake scenarios

The generation of earthquake scenarios is the first link in the prevention chain and the first step in the process of seismic risk evaluation. The implementation of the earthquake scenarios into the policies for seismic risk reduction will allow focusing on the prevention of earthquake effects rather than on overcoming/ following disasters. Bulgaria contains important industrial areas that face considerable earthquake risk. The approach adopted in the FP5 Project Risk EU (2001-2004) was used to generate earthquake scenarios for some cities in Bulgaria. The scenarios may be efficiently used for the purpose of microzonation, urban planning, retrofitting or insurance of the built environment, etc. Deterministic earthquake scenarios (expressed in seismic intensity) consistent with the disaggregation results and seismic history for some of the largest Bulgarian cities are generated.

Earthquake scenarios for the city of Sofia

The city of Sofia is the capital of Bulgaria. It is situated in the centre of the Sofia area that is the most populated (the population is of more than 1.5 mil. inhabitants), industrial and cultural region of Bulgaria that faces considerable earthquake risk. In 19th century the city of Sofia has experienced two strong earthquakes: the 1818 earthquake with epicentral intensity I_0=VIII-IX MSK and the 1858 earthquake with I_0=IX-X MSK (recently revised value in terms of EMS98 proves to be the same). The 1858 earthquake caused heavy destruction in the town of Sofia and the appearance of thermal springs in the western part of the town. During the 20th century the strongest event occurred in the vicinity of the city of Sofia is the 1917 earthquake with Ms=5.3 (I_0=VII-VIII MSK64). Almost a century later (95 years after the 1917 earthquake), an earthquake of moment magnitude 5.6 hit Sofia seismic zone, on May 22nd, 2012, located at 25 km south west of the city of Sofia.

Deterministic scenarios (Fig. 8) that are consistent with the seismic history of the city of Sofia are generated and presented in Solakov, Simeonova (2006). The PGA and SA(T) were used as output parameters for deterministic scenarios. Both for PGA scenario and spectral acceleration scenario was chosen the 1858 earthquake with low probability of occurrence that is able to generate in the Sofia municipal area intensity IX or more. The geotechnical map for the city of Sofia has been considered in the hazard scenarios generation. The scenario PGA values range between 0.05 g and 0.3 g from southeast to northwest. The spectral amplitudes reached the values of 0.75 g for vibration period T=0.3 s in the north-western part of the city.

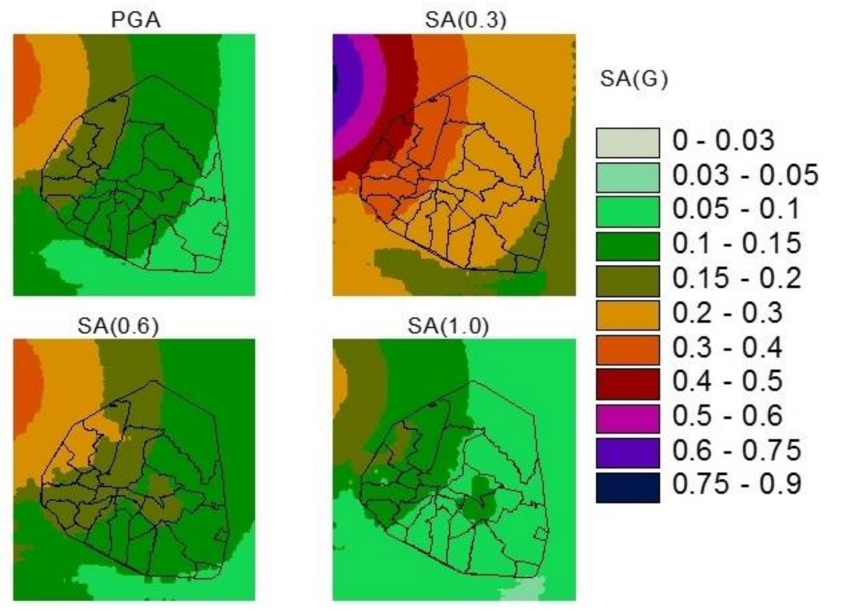
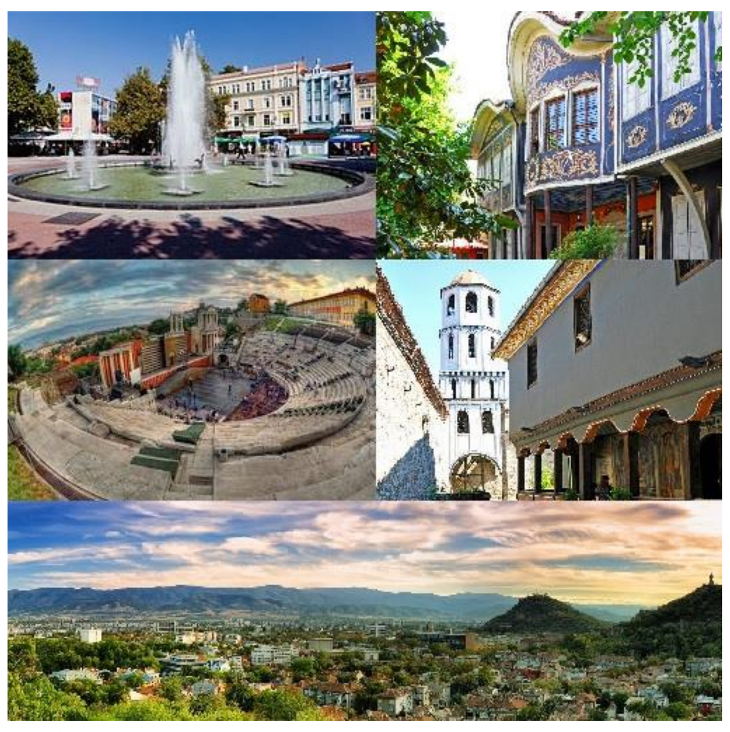


Fig. 8. Deterministic scenarios for the city of Sofia (soil corrected)



Earthquake scenarios for the city of Plovdiv

Plovdiv is one of the most populated industrial and cultural regions of Bulgaria that faces considerable earthquake risk. Over the past century, the city of Plovdiv has experienced several strong earthquakes. The earthquakes that mainly influence the hazard in Plovdiv originate near the city - the strongest earthquakes are those in 1928 (the earthquake of April 14, 1928 with M =6.8 and the earthquake of April 18, 1928 with M = 7.0, I = IX-X MSK). Base of seismic history of Plovdiv the 1928 earthquake (I=IX-X MSK) was considered as responsible of the macroseismic intensity scenarios. A deterministic scenario for the city of Plovdiv based on observed macroseismic effects caused by the 1928 earthquakes (at about 20 km) is illustrated in Fig. 9 (modified from Solakov et al., 2011).

A theoretical intensity scenario map is presented in Fig. 10. The intensity map was created using the generalized macroseismic model for earthquakes on the territory of Bulgaria presented in Glavcheva et al. (1983). The soil properties of the urban area were incorporated in the scenario generation by using a simplified geotechnical map for the city of Plovdiv. The intensity values range between 7.5 and more than 9 (MSK) and although a general decreasing trend with increasing distance from the source is obvious, a certain complexity in the spatial distribution arises because of the influence of soil conditions.

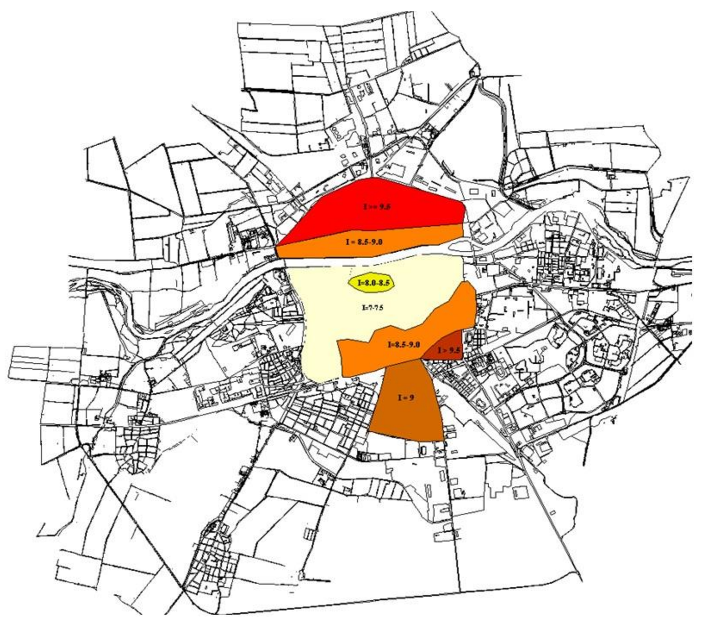


Fig. 9. Earthquake scenario for the city of Plovdiv (in intensity MSK) based on macroseimic effects

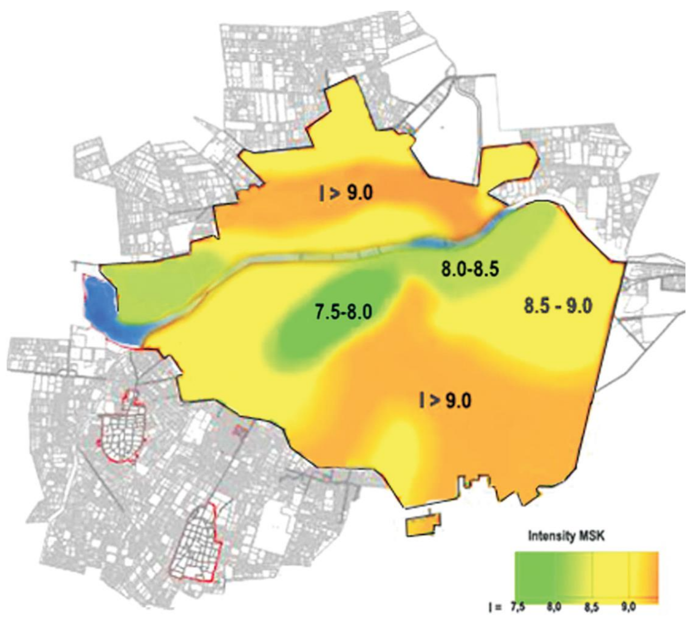


Fig. 10. Theoretical intensity scenario mapfor the city of Plovdiv

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