Earthquake scenarios for the city of Sofia

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Introduction

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 1.2 mil. inhabitants), industrial and cultural region of Bulgaria that faces considerable earthquake risk. Over the past centuries, the city of Sofia has experienced strong earthquakes: the 1818 earthquake with epicentral intensity VIII-IX MSK 64, the 1858 earthquake with I_O=IX-X MSK 64 and the M=6.5 quake in 1905. However, no such large earthquakes have occurred in the Sofia area since 1905, which may induce non-professionals to underestimate the earthquake risk. Sofia represents a typical example of high seismic risk area in the central Balkans. A strong earthquake in the Sofia area can have disastrous consequences in a large region. The present study is a comprehensive earthquake damage scenario study.



Fig. 1. Geotechnical map for the Sofia municipal area that was incorporated in the earthquake scenarios generation

Geological outline

The eastern part of the Balkan Peninsula is an element of the continental margin of Eurasia from a plate-tectonic point of view. The neotectonic movements on the Balkan Peninsula were controlled by extensional collapse of the Late Alpin orogen, and were influenced by extension behind the Aeagean arc and by the complicated vertical and horizontal movements in the Pannonian region (Zagorcev, 1992).

The basement rocks of the Sofia municipal area and slopes of the surrounding mountains are of diverse petrographic composition and age. The main geotechnical units were grouped into 3 soil classes, according to the $V_{s,\,10}$ values, which are consistent with the soil classification adopted in the main seismic codes (CEN, 2001 EUROCODE 8—Part 1).

Seismicity

The spatial pattern of seismicity in the region surrounding the Sofia municipality (within a radius of 200 km) is shown in the fig. 2. The figure represents the epicentral map of the earthquakes with M≥4.0 that occurred in the considered region. The map

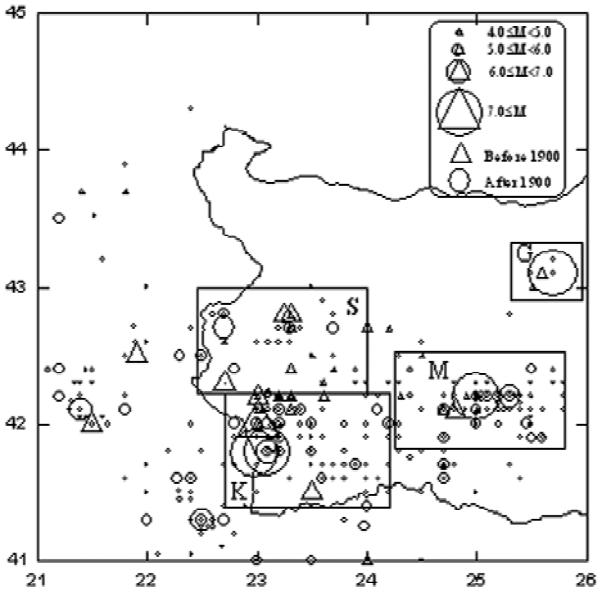


Fig. 2. Seismicity in the region surrounding Sofia municipal area (S — Sofia Seismic Zone; M — Maritsa Seismic Zone; K — Kresna Seismic Zone; G — Gorna Oriahovitza Seismic Zone)

shows that seismicity in the region is not uniformly distributed. Therefore the regional seismicity is described in distributed geographical zones-seismic zones (as shown in the figure). From the seismotectonic analysis of the central Balkans this seems more appropriate than specific fault linear structures or three-dimensional fault planes. Its own specific tectonic, seismic, and geological particulars characterize each zone. The Sofia municipal area coincide with the Sofia Seismic Zone, which is marked down by, symbol S in the figure.

Deterministic seismic hazard evaluation for the city of Sofia

In the present study the deterministic hazard is consistent with the seismic history of the city and seismic parameters of the nearest sources. 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 contemporary tectonic activity of the Sofia area is associated predominantly with marginal faults of Sofia Graben. The boundaries of the graben are represented by SE-NW fault systems with expressive neotectonic activity. Earthquakes in the Sofia Zone seem to be distributed along these fault systems, which have played an active role in the recent geodynamic evolution of the area. The western segments of marginal fault system appear to be the most probable source for earthquakes (such as here considered 1818 and 1858 events) heavily damaging the city of Sofia. Thus, the simplified source representation is adopted that consists of: SE-NW trending (striking N 124°), normal fault at a minimum distance of 15 km from the centre of the city.

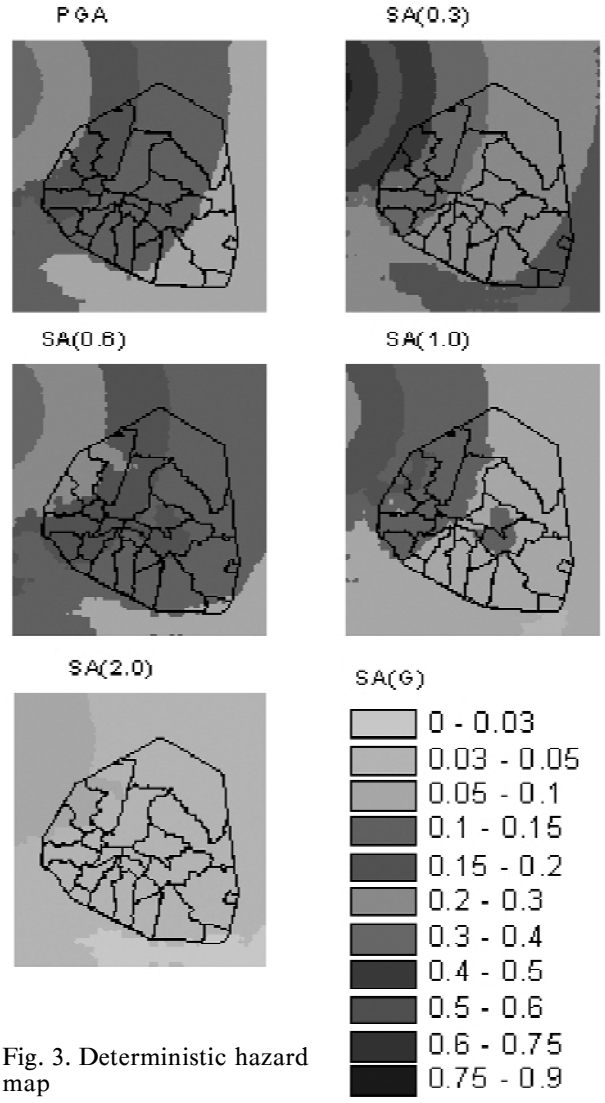


Fig. 3. Deterministic hazard map

Ground motion attenuation

In the present study is decided to adopt the attenuation relationships proposed by Ambraseys et al. (1996) as being the best fit to the goal of the present earthquake scenario study. Hence, all the maps in the later sections of the present study were computed in terms of PGA and acceleration response spectrum ordinates using the expression:

$$\log_{10}Y = C_1 + C_2*M + C_4*\log_{10}(R^2+h^2)^{1/2} + C_aS_a + C_sS_s + \sigma*P$$

where Y = Y(T) is the spectral acceleration as a function of period T, expressed in units of g or m/s^2.

The scenario spectral accelerations

Ground shaking scenarios have been generated both in terms of Peak Ground Acceleration (PGA) and of response spectral accelerations, SA(T) for different values of the vibration period T. The geotechnical map for the city of Sofia has been considered in the hazard scenarios generation. The values of PGA and SA(T) for T=0.3, 0.6, 1.0 and 2.0 were calculated at a grid interval of 0.01 degree. The considered ground motion parameters were computed in g for the M=6.3 earthquake (fig. 3). 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 municipality.

Probabilistic seismic hazard analysis for the city of Sofia

The probabilistic seismic hazard analysis (PSHA) is performed, using the so-called deductive method, which deduces what are the causative sources, characteristics, and ground motions for future earthquakes. This method was first published by Cornell (1968), with many applications since. Following the recommendation agreed among whole the project RISK-UE partners, the PSHA was performed by using machine code CRISIS99.

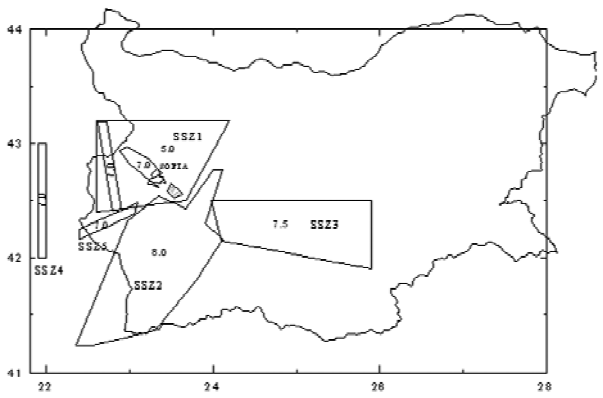


Fig. 4. Seismic source model used in the analysis

Seismic sources and seismicity parameters

Seismicity in the Sofia area and its surroundings (within a radius of 200 km) was modelled by areal sources (SSZ), each of which is deemed to be uniform in the character of its seismicity. In this particular study a seismic source model that is derived from the seismic zoning of Bulgaria (Boncev et al., 1982) is used. An equal probability that an earthquake could occur in any place within a single source zone is assumed.

A Poisson process is assumed as a time-of-occurrence model for each seismic source zone. Consequently the seismicity statistics are defined by specifying the magnitude-frequency relation with the annual seismic rate parameter, λ, the *b*-value of the Gutenberg-Richter exponential relation, the minimum magnitude, M_{min} and the maximum possible magnitude, M_{max}. The parameters λ and *b* were calculated, considering only the main events with magnitude larger than, or equal to 4.0 for each seismic source zone. The M_{max} we used in the analysis are the maximum expected magnitudes proposed by Boncev et al. (1982) and presented in figure 4.

Scenario peak ground and spectral accelerations

The probabilistic scenario maps have been generated both in terms of Peak Ground Acceleration (PGA) and of response spectral accelerations, SA(T) for different values of the vibration period T (fig. 5). Values (in g) of the ground motion parameters were calculated at a grid interval of 0.01° using the attenuation relations of Ambraseys et al. (1996). Figure 5 displays the seismic hazard for a 475 year return period expressed in PGA, SA(0.3), SA(0.6), SA(1.0) and SA(2.0). The estimated PGA for the city of Sofia is varying between 0.15-0.28 g for rock soil conditions.

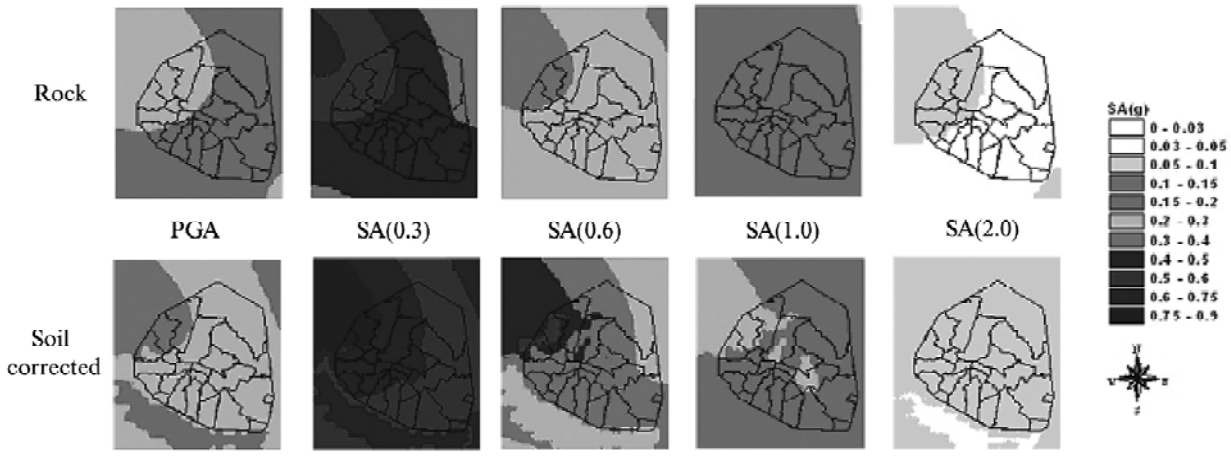


Fig. 5. Probabilistic hazard maps for the city of Sofia

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Земетръсни сценарии за град София

Димо Солаков, Стела Симеонова

Резюме. Град София, който е главен административен център на България с висока плътност на населението, е силно сеизмично уязвим. За община София са генерирани земетръсни сценарии като са приложени вероятностен и детерминистичен подходи. В сценариите са отразени инженерногеложките условия на града. Получените хазартни сценарии могат да се използуват като изходна база за оценка на сеизмичния риск за град София. Тук представените резултати са част от българските изследванията, проведени по проект Risk EU (2001—2004), финансиран от Европейската Икономическа Комисия в рамките на 5-та Рамкова програма.