DETERMINISTIC SEISMIC SCENARIOS BASED ON MACROSEISMIC INTENSITY GENERATED BY REAL STRONG EARTHQUAKES OF THE PAST

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Abstract: The territory of Bulgaria represents a typical example of high seismic risk area. In the present study deterministic scenarios in intensity for two Bulgarian cities (Ruse and Plovdiv) are presented. By deterministic scenario it is mean a representation of the severity of ground shaking over an urban area, using one or more hazard descriptors. Such representation can be obtained: - either from the assumption of a "reference earthquake" specified by a magnitude or an epicentral intensity, associated to a particular earthquake source - or, directly, showing values of local macroseimic intensity generated by a damaging, real earthquakes of the past. In the study we chose for the second method using the values of macroseimic intensity caused by damaging historical earthquakes (the 1928 quakes in southern Bulgaria; and the 1940 and the 1977 Vrancea intermediate earthquakes).

Key words: earthquake, seismic impact, macroseismic intensity, deterministic scenarios, seismogenic area.

Introduction

Earthquakes are the most deadly of the natural disasters affecting the human environment; indeed catastrophic earthquakes have marked the whole human history. Global seismic hazard and vulnerability to earthquakes are increasing steadily as urbanization and development occupy more areas that are prone to effects of strong earthquakes. Additionally, the uncontrolled growth of mega cities in highly seismic areas around the world is often associated with the construction of seismically unsafe buildings and infrastructures, and undertaken with an insufficient knowledge of the regional seismicity peculiarities and seismic hazard. The assessment of seismic hazard and generation of earthquake scenarios is the first link in the prevention chain and the first step in the evaluation of the seismic risk.

Bulgaria situated in the Balkan Peninsula (that is a part of the Alpo-Himalayan seismic belt, which is characterized by high seismicity) is exposed to a high seismic risk. Bulgaria contains important industrial areas that face considerable earthquake risk. Over the centuries, Bulgaria has experienced strong earthquakes. Some of the Europe¢s strongest earthquakes in 20-th century occurred on the territory of Bulgaria. Impressive seismic activity developed in the SW Bulgaria during 1904-1906. The seismic sequence started on 4 of April 1904 with two catastrophic earthquakes within 23 minutes (the first quake with MS=7.1 considered as a foreshock and the second, the main shock, with MS=7.8 and I0=X). Along the Maritza valley (central part of Bulgaria), a sequence of three destructive earthquakes occurred in 1928. However, no such large earthquakes occurred in Bulgaria since 1928, which may induce non-professionals to underestimate the earthquake risk. Moreover, the seismicity of the neighboring countries, like Greece, Turkey, former Yugoslavia and Romania (especially Vrancea-Romania intermediate earthquakes), influences the seismic hazard for Bulgaria.

In the present study deterministic scenarios (expressed in seismic intensity) for the cities of Plovdiv and Rouse are presented. Both deterministic scenarios were generated using the values of macroseimic intensity cased by damaging, real earthquakes of the past. The methodology applied is described among others in Solakov et al., 2009 and Solakov et al., 2011. The work on scenarios was guided by the perception that usable and realistic (also in the sense of being compatible with seismic histories of cities that are several centuries long) ground motion maps had to be produced for urban areas.

Earthquake senario for the city of Plovdiv

The city of Plovdiv

Now

19th century **Ancient time**

The Bulgarian city of Plovdiv is located in the South-Central Bulgaria on the two banks of the Maritsa River. Being the second largest city in the country, it has a population of about 350 000. The city has historically developed on seven syenite hills, some of which are 250 m high. Because of these seven hills, Plovdiv is often referred to in Bulgaria as "The City of the Seven Hills". History of the city of Plovdiv spans some 6,000 years, with traces of a Neolithic settlement dating to roughly 4000 BC. In the beginning of the 20th century Plovdiv grew as a significant industrial and commercial center. At present Plovdiv is one of the most populated cultural region 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 of Plovdiv originate near the city. The contemporary tectonic activity of the area is associated with Maritsa fault system with WNW-ESE direction. The Maritsa fault with its satellites belongs to structures with a longlasting development, which continues in the neotectonic period. The oblique Maritsa Fault striking N 116º, and the dipping towards N is of length of about 36 km. It is known with the surface rupturing during the MW = 7.0 earthquake of 18 of April 1928 (Yankov, 1945). The strongest known earthquakes occurred on the fault system are those in 1928 (the Chirpan earthquake of April 14, 1928 with MW=6.8 and the Plovdiv earthquake of April 18, 1928 with MW=7.0, I= 9-10 MSK). The 1928 earthquakes completely destroyed 74000 buildings in the towns of Plovdiv, Chirpan and Parvomay (Kirov, 1945).

The 1928 M_W7.0 earthquake impact on the city of Plovdiv

The 1928 earthquake ruined 3600 and partially destroyed 6000 buildings in the city of Plovdiv (DIPOZE, 1931). Some of the damages in the city of Plovdiv are illustrated in Fig. 1.

Fig. 1. Damages in the city of Plovdiv caused by the 1928 (M_W=7.0) earthquake

In the present study the earthquake damages are assessed on the base of descriptions and analyses presented in DIPOZE ,1931. Additionally, available documents and materials that were collected in the territorial Directorate "State Archive" and the National Library "Ivan Vazov", Plovdiv were used.

The most of the destructions have been observed north of the Maritsa River due to very bad soil conditions and not well constructed buildings. The maximum observed intensity there reaches 9-10th degree MSK.

One of the worst hit districts is, located in the southeast part of the city. The district is built on drought and loose sleeve of the Maritsa River. 95% of the houses there were destroyed. The intensity of the impact in this region is higher than 9th degree MSK.

Major damages have been identified in the southern marginal part of the city (the size of the city of Plovdiv in 1928 is considerably smaller than the current size of the city) where the buildings are small, ramshackle homes built without any supporting structures. The impact is assessed by intensity 9th degree MSK.

Overall the city center and houses around the hills have suffered slight damage. South of Maritza River damage on buildings are considerably smaller. The public and private buildings are well built and the soil conditions are stable - compacted sediments. The maximum observed intensity in that part of the city is 7–8th degree MSK. Least affected are buildings situated on and around the hills. The houses are solid with thick stone walls situates on syenite hills. The maximum seismic intensity in this area is 7th degree MSK.

Observed damage can be regarded as a combined effect of seismic impact, geological conditions and the type of construction.

Distribution of macroseismic effects (in intensity) along the city of Plovdiv is presented in Fig. 2.

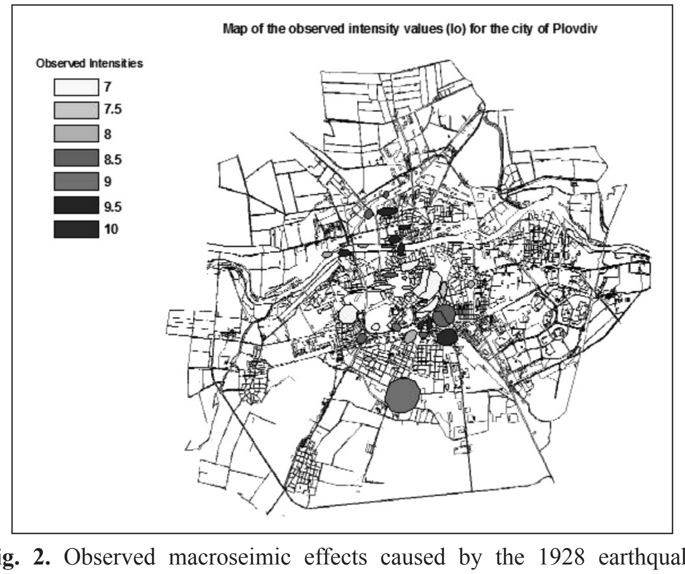

Fig. 2. Observed macroseimic effects caused by the 1928 earthquake (M_W =7.0) on the city of Plovdiv (in intensity MSK);colore represent the intensities in MSK scale;**(**Map of Plovdiv from the beginning 20th century**)**

The intensity scenario map is presented in Fig. 3. Base of seismic history of the city of Plovdiv the 1928 earthquake (M_W =7.0) is considered as responsible of the macroseismic intensity scenario. The generation of intensity scenario use directly the intensity assessment of the 1928 quake with M_W=7.0. The scenario map illustrates the distribution of the maximum values of macroseismic intensity (MSK) along the central part of the city of Plovdiv. The soil properties of the urban area were incorporated in the senario generation by using the very simplified geotechnical map for the city of Plovdiv.

Fig. 3. Earthquake scenario for the city of Plovdiv (in intensity MSK) based on macroseimic effects generated by a damaging, real earthquake of the past; colors represent the intensities in MSK scale. (Map of Plovdiv from the beginning 20th century)

Earthquake scenario for the city of Ruse

The city of Ruse

The city of Ruse that is located in the north-eastern part of the country is the fifth largest city in Bulgaria. Its population is about 162000 people. The city of Ruse is situated on the right bank of the Danube River, in the mouth of Rusenski Lom River. It is the most significant Bulgarian river port, serving an important part of the international trade of the country.

The city emerged as a Neolithic settlement from the 3rd to 2nd millennium BCE, when pottery, fishing, agriculture, and hunting developed. During the reign of Vespasian (69-70 CE) it developed into a Roman military and naval centre as part of the fortification system along the northern boundary of Moesia. Its name, Sexaginta Prista, suggests a meaning of “the port town of the sixty ships. After it became part of modern Bulgaria on 20 February 1878, Ruse was one of the key cultural and economic centres of the country. Intensive building during the end of the 19th and the beginning of the 20th century changed the city’s architectural appearance to a typical Central European one. The city is famous for its 19th- and 20th-century Neo-Baroque and Neo-Rococo architecture, which attracts many tourists. It is often called the Little Vienna.

Now

Bank "Girdap" - built in1881 **National theatre -** built 1898-1902

Ancient "Sexaginta Prista" **Ruse in 1824**

The Vrancea seismogenic zone of Romania is a very peculiar seismic source, often described as unique in the world, and it represents a major concern for most of the northern part of Bulgaria. The events generated in this seismogenic zone are characterized by relatively deep hypocenters and wide area of marcoseismic impact. In this area strong intermediate-focused earthquakes are being realized with depth 90-230 km. The strongest known events, occurred in the Vrancea seismogenic zone are the following earthquakes: the 1802 quake with magnitude M_W=7.9 (Watzof, 1902), the 1940 M_W=7.7 (Kirov, 1941) and the 1977 quake, M_W=7.4 (the Mw estimates are according to ROMPLUS, 2007). Situated at distances larger than 200 km from the Vrancea zone, several cities in the northern Bulgaria suffered many damages due to high energy Vrancea intermediate-depth earthquakes. The March 4, 1977 event (Mw 7.4) caused partial or total damages in 8470 buildings (as illustrated in Fig. 4), and 125 casualties on the territory of Bulgaria.

Fig. 4. Damages in Northern Bulgaria caused by the 1977 (M=7.2) Vrancea earthquake

Impact of Vrancea earthquakes on the city of Ruse

The strongest documented seismic impacts on the city of Ruse until nowadays are from earthquakes generated in Vrancea seismogenic zone. In the present study two intermediate-focused Vrancea earthquakes are considered: the 1940 (M_W=7.7) and the 1977 (M_W=7.4).

For both earthquakes distribution of macroseismic effects along the city is estimated on the base of documents available in Regional administration of “State Archive” and Regional Library “L.Karavelov”, Ruse.

The intensity map illustrating the impact of the 1940 M_W7.7 earthquake on the city of Ruse is presented in Fig.5. The figure shows that the intensity values range between 6 and 7 MSK. The most affected are the central and the coastal areas of city of Ruse.

Distribution of macroseismic effects (in intensity) of the 1977 M_W7.4 earthquake along the city of Ruse is presented in Fig.6. The highest intensities (7-8MSK) are observed in the west-southwest, central and coastal part of the city where the intensity reaches the 9^{th} MSK.

The observed distribution of intensity function along the city of Ruse in both cases is identical (though a scant information about the earthquake of 1940). Impacts of the both earthquakes are with the highest intensity in coastal parts of the city. Strong effects are observed in the western and central parts of the city of Ruse. In the central and western parts of the city buildings and facilities were built on subsiding loess soils. The water content of these soils is increased by the proximity of the river Rousse Lom River and aquifers formed the basis of loess, leading amending strength-deformation characteristics.

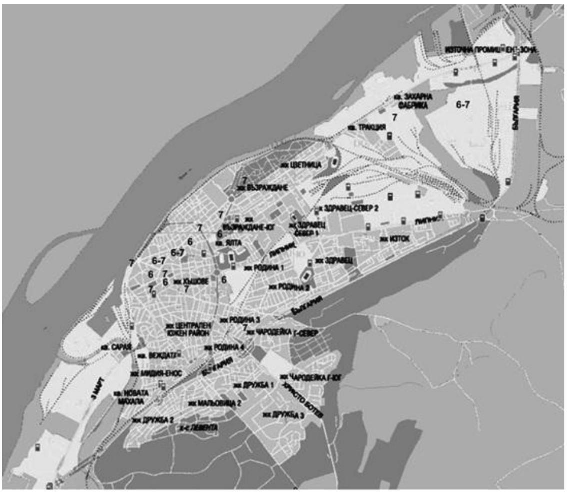

Fig. 5. Impact of the 1940 Vrancea earthquake (M_W=7.7) on the city of Ruse; the numbers represent the intensities in MSK scale.

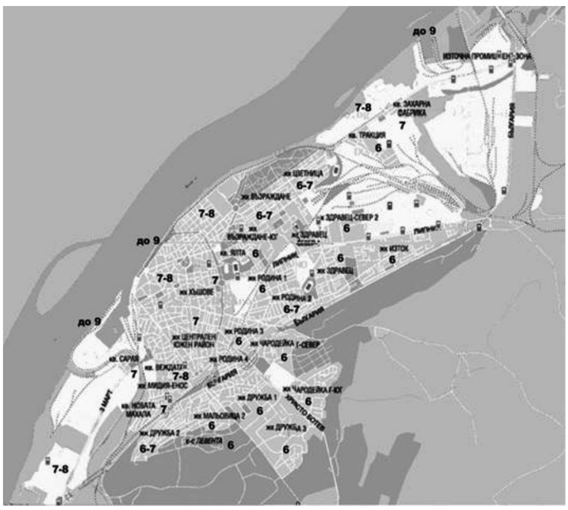

Fig. 6. Impact of the 1977 Vrancea earthquake (M_W=7.4) on the city of Rus; numbers represent the intensities in MSK scale

The earthquake scenario (in intensity) for the city of Ruse is presented in Fig.7. The generation of intensity scenario used directly assessed impacts of the strongest past intermediate-focused earthquakes-the 1940 quake with M_W=7.7 and the 1977 quake with $M_{W=}$ 7.4, both generated in Vrancea, Romania. A good spatial coincidence between the value of the impacts assessed and configuration of the Danube and Ruse Lom Rivers terraces was found. The seismic scenario for the city of Ruse (presented in Figure 7) is generated by matching the observed distribution of intensity function along the city with the configuration of river terraces. The scenario map illustrates the distribution of the maximum values of macroseismic intensity (in MSK) along the city of Ruse.

Fig. 7. Earthquake scenario for the city of Ruse (in intensity MSK) based on macroseimic effects generated by damaging, real earthquakes of the past; colors represents the intensities in MSK scale.

Conclusions

Such scenarios are intended as a basic input for developing detailed earthquake damayge scenarios for the cities. They can be used also to improve urban development and for risk mapping and management

The scenarios may be efficiently used for the purpose of microzonation, urban planning, retrofitting or insurance of the built environment and infrastructure planning, etc.

The damages caused by these earthquakes have outlined the need of in-depth analysis in what concerns the seismic hazard specific for the regions, as well as the need to suggest solutions to reduce the possible negative effects.

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 intervention following the disasters.

It is hoped that the themes inherent in the analysis of seismic hazard and risk, aimed at the conservation of the historical architectural heritage and the detailed knowledge of a territory, may inspire a new "historic" awareness of environmental risk.

All these concerns may enter into the world of schools and be propagated by the mass media, in the forms best suited to arouse the interest of the young generation and to stimulate in them the need for a culture of safety and prevention as a new form of habitation civilization.

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Детерминистични сеизмични сценарии, базирани на макросеизмични интензивности, генерирани от силни земетресения реализирани в миналото

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Резюме. България представлява типичен пример за територия с висока степен на сеизмична опасност. В настоящото изследване са представени детерминистични сценарии в макросеизмична интензивност за два големи българси града (Русе и Пловдив). Детерминистичният сценарий е една оценкаа на най-силните възможни сеизмични въздействия върху урбанизираната територия. Такъв сценарий се генерира: – или чрез използване на „референтно земетресение“ с определен магнитуд (или епицентралната интензивност), свързано с конкретен сеизмичен източник – или директно, чрез изпозуване на наблюдавани въздействия, причинени от разрушителни земетресения, реализирани в миналото. В иастоящото изследване е избран вторият подход като са приложени наблюдаваните макросеизмични въздействия, причинени от силни исторически земетресения – събитията, генерирани в южна България през 1928 г., и земетресенията от 1940 г. и 1977 г., реализирани в междиннофокусно огнище Вранча.