PROBABILISTIC SEISMIC HAZARD ASSESMENT FOR BULGARIA AS A BASIS FOR A NEW NATIONAL BUILDING CODE

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INVESTIGATED TERRITORY AND SCOPE

- The territory of Bulgaria - a typical example of high seismic risk area in the eastern part of the Balkan Peninsula. Bulgaria contains important industrial areas facing considerable earthquake risk. Moreover, the seismicity of the neighboring countries, like Greece, Turkey, former Yugoslavia and especially Vrancea-Romania intermediate earthquakes influences the seismic hazard in Bulgaria as well.
- 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.
- Seismic hazard maps for the New National Building Code of Bulgaria were developed using the procedure showed in Fig. 1. The basic approach used for the creation of ground motion maps incorporate in GIS mode the source-geometry, earthquake occurrence model, the strength of the earthquake sources, and the appropriate attenuation relations.

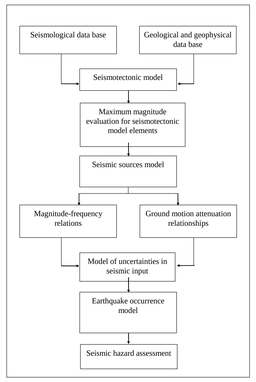


Fig.1 Flowchart for seismic hazard assessment

INPUTS TO THE PROBABILISTIC SEISMIC HAZARD ANALYSIS (PSHA)

- The most important input required is an **earthquake catalogue** for the region of the study. For this purpose a catalogue for the region bordered by 39.5° - 47.5° N and 19°- 30° E was compiled (25 000 earthquakes). Data are unified and standardized in accordance with requirements of the international seismological centers. The intensity estimations are based on MSK intensity scale and the magnitude estimations are equivalent to M_S magnitude scale. Using a space-time magnitude dependent window the aftershocks were identified and removed. The threshold magnitude M_S=4.0 was accepted in order to insure space homogeneity (over the territory of Bulgaria) of the catalogue data.

From the analysis of the depth distribution it was recognized that most of earthquakes in the considered region are shallow (the maximum density of seismicity involves the layer between 5 and 25 km). Vrancea area (in Romania) is the only part of the considered region that is characterized with the occurrence of intermediate earthquakes (h>60km up to 200 km).

- Additionally, for intermediate earthquakes in Vrancea (Romania), a new Romanian catalogue (ROMPLUS) was also considered. The size of the quakes is given in terms of moment magnitude M_W.

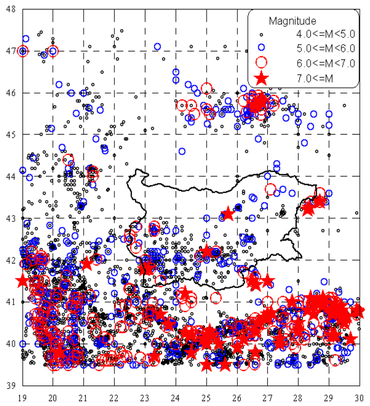


Fig. 2. The spatial pattern of seismicity for the considered region (within a space window 39.5°- 47.5° N and 19°- 30° E, M≥4.0)

SEISMIC HAZARD ANALYSIS

In the present study a PSHA was performed, using the so-called deductive method, which deduces what are the causative sources, characteristics, and ground motions for future earthquakes (McGuire, 1993). More specifically, a version of machine code EQRISK (McGuire, 1976), is used with PGA as a hazard parameter. The version of machine code EQRISK was developed and used in practice for probabilistic hazard assessment in Bulgaria. It gives the following advantages: 1) usage of different types of attenuation models, including arbitrary functions of M, R and h; 2) allows different types of laws for different sources; 3) depth is included as a random uncertainty (each source is described with its own depth distribution); 4) source mechanism is included as a random uncertainty;

A)

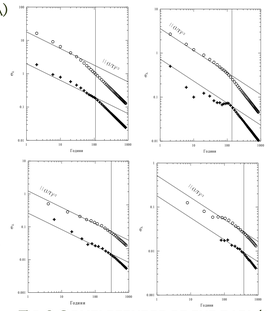
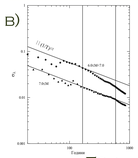


Fig.3 Completeness of the data (a-shallow quakes and b –intermediate)

5) allows point and circle sources as well as sources between 2 circles with a common center; 6) allows non continuous sources and fault sources; 7) allows Monte-Carlo sensitive analysis; 8) computation of hazard in terms of PGA and spectral amplitudes could be performed with one run of the program.

The seismic hazard map for PGA on rock corresponding to the 475 years return period is presented in Fig.6a. To limit the damage of buildings and financial loss in case of weaker earthquakes with higher frequency of occurrence, a second hazard level in EC8 is recommended, corresponding to a recurrence period of 95 years (Fig. 6b). Both hazard maps are generated in ArcGIS 9.2.

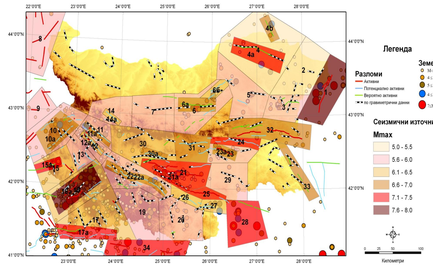
B)

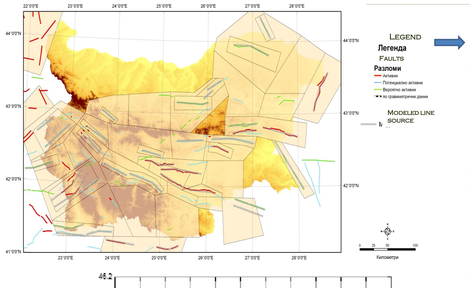


Because the compiled catalogue is used for seismic hazard analyses it was necessary to examine the completeness of the data using Stepp's test (1971). The test was applied to shallow and intermediate earthquakes separately (Fig.3 a) and b). The results show that the compiled catalogue for shallow earthquakes can be considered complete in the last 400 years for magnitudes larger than 7.0; 250-300 years for M_S≥6.0; 120 years for M_S≥5.0 and after 1900 for M_S≥4.0 (Fig. 3a).

For intermediate earthquakes (in Vrancea, Romania) the Stepp's test indicates that the ROMPLUS catalogue can be considered complete in the last 600 years for magnitude larger than or equal to 7.0 (M_W≥7.0) and about 200 years for M_W≥6.0 (Fig.3b). The test results imply that it is possible to create homogeneous data samples by determining intervals over which earthquakes in different magnitude classes are completely reported.

- The second required input is a **designation of earthquake sources** in the considered region. In the present study seismic sources were identified on the base of comparison of the geological and geophysical data with the seismological information (historical and instrumental seismicity.) The basic characteristics (geometry, geographical extend, earthquake recurrence and maximum earthquake magnitude) and relation to the regional tectonic framework for each seismic source were defined. Two alternative source models were generated (Fig. 4).





Thus the compiled seismic source model consists of simple area sources and mixed type area sources. The seismic source Vrancea was divided to two sub-sources V1 and V2 (based on epicentral density function) with uniform earthquake frequency and different estimates for maximum potential earthquake magnitude. Uniform depth distribution in different ranges ([100-150] km for V1 and [80-150] for V2) is assumed for both Vrancea sub sources (Fig.5).

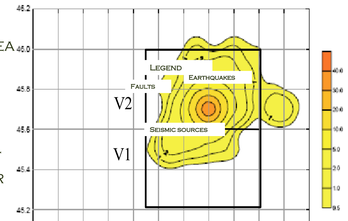


Fig.5 Epicenter density function for Vrancea, intermediate, zone

- The third required input is the **earthquake occurrence model.** In the present study a truncated exponential distribution is assumed as seismicity model for each seismic source. The estimated b-values range from 0.6 to 0.8 and from 0.6 to 0.9 for seismic sources in and outside Bulgaria respectively. Magnitude of the maximum potential earthquakes (M_{MAX}) for seismic sources in Bulgaria was estimated using functions that relate magnitude to length of the defined tectonic structures in the region (relations used in the analysis are presented in Wells and Coppersmith, (1994). The M_{MAX} estimates are matched to the maximum expected magnitudes that are proposed by Boncev et al. (1982).
- A final input required is a **designation of a ground motion attenuation relationship**. The attenuation relationship proposed by Ambraseys et al. (1996) was chosen for the present study. It is based mostly on European data and a simplified soil classification is used. It covers large ranges in distance (up to 200 km) and magnitude (4.0≤M≤7.5). The PGA(g) is given by the expression. For shallow earthquakes:

$$\log_{10}Y=-1.48 + 0.266*M-0.992*\log10(R^2+3.5^2)^{1/2}+0.117*S_A+0.124*S_S\pm\sigma \quad (1)$$

where R – distance in km; M-earthquake surface wave magnitude, M_S; S_A, S_S-coefficient for the site geology [rock: (S_A, S_S) = (0,0); stiff: (S_A, S_S) =(1,0); soft soil: (S_A, S_S) = (0,1)]; σ denotes the standard deviation.

For intermediate earthquakes: Attenuation model for PGA presented in Lungu et al. (2000) is used in hazard calculations for Vrancea intermediate earthquake. The model is given by relation:

$$\ln(PGA)=3.098+1.053*M*\ln(R)-0.0005*R-0.006*H\pm\sigma \quad (2)$$

where M-earthquake moment magnitude, M_W, R is hypocentral distance and H – earthquake depth.

DEAGGREGATION

De-aggregation of the seismic hazard for a recurrence period of 475 years (probability of exceedance of 10% in 50 years) for PGA was performed for 27 cities (administrative centers) on the territory of Bulgaria. The de-aggregation results show existence of both unimodal and bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA. Some of the most representative de-aggregation plots are illustrated in Figs. 7a-c.

PSHA de-aggregation plots for PGA show the following peculiarities:

1. Two types of unimodal distribution are identified:

- The mode of the distribution is for magnitude 5.0-7.5 earthquakes at a distance of about 5 to 10 km from the cities – effect of local seismic sources (the example presented in Fig. 7a is the de-aggregated hazard for the cities of Sofia and Plovdiv). The strongest contributor to the hazard (for PGA) for a recurrence period of 475 years is the near regional seismicity.
- The mode of the distribution is for magnitude greater than or equal to 7.5 earthquakes at a distance of more than 200 km from the cities – effect of Vrancea intermediate earthquakes (the example presented in Fig. 7b is the de-aggregated hazard for the for the cities of Ruse and Pleven). The strongest contributor to the hazard (for PGA) for a recurrence period of 475 years is the Vrancea intermediate source.

2. A slight bimodal distribution is illustrated in Fig. 7c

-The primary mode of the distribution) is for magnitude greater than or equal to 7.5 earthquakes at a distance of 255 to 275 km from the city-effect of Vrancea intermediate earthquakes. The secondary mode is a magnitude 5.0 to 6.0 earthquake at 10 to 20 km from the city- effect of local seismic sources. The strongest contributor to the hazard (for PGA) for a recurrence period of 475 years is the Vrancea intermediate source.

- The primary mode (well expressed) is for magnitude 5.0 to 7.0 earthquakes at a distance of 10 to 20 km from the city - effect of local seismic sources. The secondary mode (not well expressed) is for magnitude greater or equal to 7.5 earthquakes at a distance of more than 220 from the city-effect of Vrancea intermediate earthquakes. The strongest contributor to the hazard (for PGA) recurrence period of 475 years is the near regional seismicity.

3. A strong bimodal distribution of earthquake magnitude and distance to ground motion exceedance frequency is presented in Fig. 7d.

The primary mode of the distribution is for magnitude greater or equal to 7.0 earthquakes at a distance 10 to 20 km from the site - effect of local seismic sources. The secondary mode is a magnitude 7.5 or larger earthquakes at a distance of more than 250 km from the city - effect of Vrancea intermediate earthquakes (the example presented in Fig. 7d is the de-aggregated hazard for the city of Varna). The de-aggregation of the hazard (for PGA) for a recurrence period of 475 years shows that the hazard is influenced both from near region seismicity and Vrancea intermediate earthquakes

Examination of maps of hazard distributions enables the investigator to determine the distance and azimuth to predominant sources, and their magnitudes. This information can be used to generate scenario earthquakes and corresponding time histories for seismic design and retrofit.

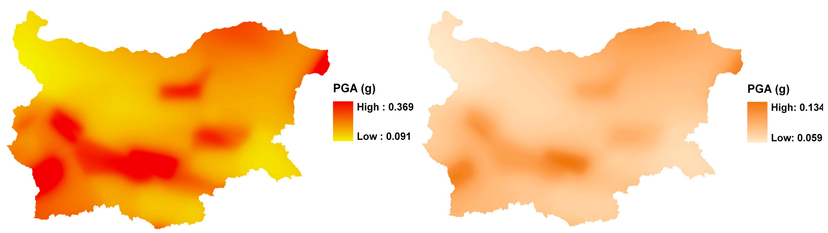


Fig.6 Seismic hazard for Bulgaria in PGA: a) for a recurrence period of 475 and b) for 95 years; column represent PGA values in g.

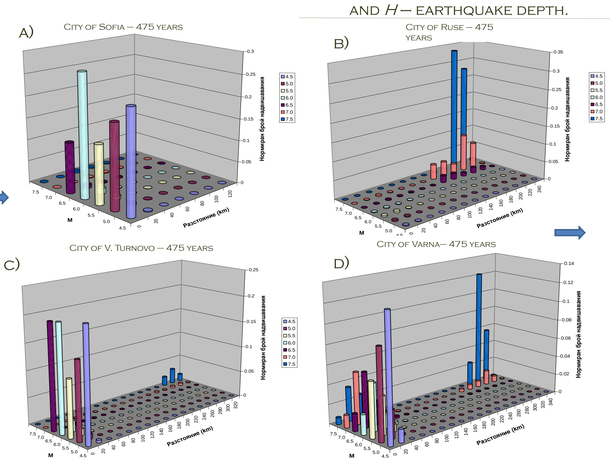


Fig.7 PSHA deaggregation showing the distribution of earthquake magnitude and distance to ground motion exceedance frequency for PGA

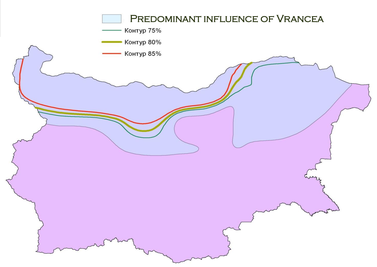


Fig.8 Region with predominant influence of Vranceaintermediate earthquakes (over 50%, 75%, 80%, 85%) on seismic hazard.

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