Annuaire de l'Université "St. Kliment Ohridski", Faculté de Physique, 99, 2006

ON THE SEISMOLOGICAL DATABASE FOR THE SEISMIC HAZARD ASSESSMENT IN THE TERRITORY OF BULGARIA AND ADJACENT LANDS

GALINA FOTEVA, EMIL BOTEV*, MINKA ILIEVA

Department of Meteorology and Geophysics
**Geophysical Institute, BAS*

Галина Фотева, Емил Ботев, Минка Илиева. ВЪРХУ СЕИЗМОЛОГИЧНИТЕ ДАННИ ЗА ОЦЕНКА НА СЕИЗМИЧНИЯ ХАЗАРТ НА ТЕРИТОРИЯТА НА БЪЛГАРИЯ И СЪСЕДНИТЕ ЗЕМИ

В статията се представят дейностите и резултатите от подготовката на сеизмологичния каталог за централната част на Балканите, съставен според изискванията на метода на Франкел (1995) за оценка на сеизмичния хазарт. Настоящият каталог е компилиран преди всичко на базата на едни от последните версии на каталозите на Христосков и др.(1981) и на ISC (2004), при съответната координация с различни национални каталози на Балканските страни. Основната отличителна черта на каталога е събраната и унифицирана максимално количество възможна информация за земетресенията с магнитуд $M \geq 2.9$ в територия с ъглови координати 40° N, 21° E–46° N, 30° E за периода от 479 пр.Хр. до 2003 г. В работата се извеждат оригинални зависимости за привеждане на различните видове магнитуд в M_S. Използвана е и процедурата за разделяне на земетресенията на основни и зависими събития. Получена е оценка за пълнотата на данните за различни периоди от време. Каталожните данни показват значимо съвпадение на епицентралните разпределения за историческо и настоящо време.

Galina Foteva, Emil Botev, Minka Ilieva. ON THE SEISMOLOGICAL DATA BASE FOR THE SEISMIC HAZARD ASSESSMENT ON THE TERRITORRY OF BULGARIA AND ADJACENT LANDS

The activities and results obtained during the preparation of the catalogue of earthquakes for a seismic hazard assessment by the method of Frankel (1995) are presented. The new prepared catalogue is highly integrated with ones of the last version of the catalogue of

Christoskov et al.(1981) and Regional catalogue of earthquakes of ISC(2004). Our new unified catalogue has some specific characteristics, most remarkable of which is that it contains all the available information about the events with $M \geq 2.9$ in the territory with the corner coordinates 40° N, 21° E–46° N, 30° E for the period from 479 BC to AD 2003. Original relations obtained for transforming of the various magnitude determinations into M_S are suggested. The procedure of separation of the data into main events and aftershocks is used. Various levels of completeness for the different time periods are obtained. As a whole the catalogue data show significant coincidence between the epicentral distribution of the historical and the recent events.

Keywords: earthquake, seismological database, catalogue, seismic hazard
PACS number: 91.30.-f

1. INTRODUCTION

The territory of Bulgaria and the adjacent lands are located in one of the most seismoactive regions of Europe. This is the Aegean zone from the East-Mediterranean region of the seismoactive Alpo-Himalayan belt. The seismic statistics of the past century for this central part of the Balkan region shows the occurrence of several strong destructive earthquakes with magnitude $M > 7.0$. The historical data from the previous centuries confirms the high seismicity of these lands and determine the importance of their seismic hazard assessment.

The most fundamental information for seismic hazard assessment comes from the earthquake catalogues. In the present paper the activities and results obtained during the preparation of the unified catalog of earthquakes for the central part of Balkan region are presented. The estimation of the seismic hazard by the modern method of spatially smoothed seismicity, proposed by Frankel (unused so far for the territory of Bulgaria and adjacent lands) is the main goal of the authors.

First version of the method of Frankel [1] is applied primarily in USA during 1995 as an alternative of the well known technique of McGuire [2] based on the Cornel approach [3]. Later the method of spatially smoothed seismicity was modified by Frankel et all.[4]. A modified variant of the Frankel approach [5, 6] is used for a seismic hazard assessment of Slovenia territory (in the central part of Europe). The specific Frankel's approach concerning the initial seismological information takes into account the weak seismicity in and around the region of interest. This peculiarity leads to the preparation of a large catalogue of earthquakes ($M \geq 2.9$) for the significantly larger territory around Bulgaria (central part of Balkan region).

2. INITIAL CATALOGUE OF SEISMOLOGICAL DATA

A few catalogues of historical and recent earthquakes exist for the investigated region. Earthquake data used in the present study are selected mainly from the Christoskov et al [7] (with 1649 events in the Central Balkans for the period 479 BC–AD 1977), which had been used for the last official seismic prognostic zonation of Bulgaria and adjacent regions [8]). For the next period (1978–2003) the working bulletins of the Bulgarian seismological network (Founds of Geophysical Institute of BAS) are used, as well as the official published catalogues data in the Bulgaria Catalogue of Earthquakes 1981–1990 [9] and in the Botev et all.[10] for the territory of Bulgaria and the closed vicinities. For the various adjacent lands and time periods the data from the Balkan catalogue of UNESCO [11], Greek catalogue [12], Catalogue of Turkey earthquakes [13], as well as much more data from Regional catalogue of earthquakes of ISC [14] are used. All the available materials about the earthquakes are worked out together in order to be presented in a uniform form. The compilation is realized by means of checking, correlation and correcting of the instrumental and macroseismic data in order to obtain homogeneity in the estimations of earthquake parameters. It is important to note that our compiled catalogue is highly integrated with the last version of Regional catalog of earthquakes of ISC, revised in 2004. All useful information from this catalogue, as well as from the national catalogues of the neighbor countries were used for the events located around Bulgarian territory. Information from different seismological centers is included in our catalogue for one and the same event. A priority of the catalogues [7] [9] and [10] is given in the cases of duplicated events for the Bulgarian territory (41°–44.3° N; 22°–29° E), and for the southern belt with coordinates 40°–41° N and 21°–30° E the catalogue [12] is preferable. The new unified catalogue considers all events which epicenters are included in a polygon comprising of the seismoactive zone of interest for hazard assessment in Bulgaria. In such a way one common catalogue file is compiled for more than 10311 earthquakes with magnitude $M \geq 2.9$, which epicenters are included in the territory limited by the corner coordinates 40° N, 21° E–46° N, 30° E and so obtained for the period since 479 BC to AD 2003. For each earthquake the most necessary parameters are presented as follows:

- Date and Time (GMT) of earthquake occurrence;
- Epicentral coordinates (geographic latitude and longitude);
- Hypocentral depth;
- Magnitude, different kind reported;
- Intensity, if is available (MSK);

• Number of stations used for the parameter determination;
• Abbreviation of the seismological center or source of the information.

3. SOME PROBLEMS IN THE PREPERATION OF CATALOGUE FOR HAZARD PURPOSES

There are no established standards on the specific contents of the seismic catalogues and on the standardization of its parameters. For many events in our compiled catalogue, different information from different sources is included. Many efforts are needed to achieve some objective estimation of the level of homogeneity and completeness of the data parameters according to the requirements of the seismic hazard assessment.

In order to make the catalogue useful for hazard estimates the authors decided to compile the value of a reference magnitude for each event. The exact determination of magnitude measured on recordings is very complicated problem. It results to many differences in the magnitude values for one of the same event calculated at different seismological centers. The most frequently magnitude determinations in our main initial catalogues [7] and Regional catalogue of ISC, 2004 [14] are surface-wave magnitudes (M_S). M_S is the most widely used magnitude scale for large earthquakes, but it cannot characterize deep or relatively small regional end local events. The frequently referred in ISC catalogues $\mathrm{m_b}$ scales widely is used to characterize the deep events, but also it is very hard to estimate adequately the magnitude of relatively small regional and local events. That is the reason M_d (magnitude determined by "signal" duration) and M_L (local magnitude) to be the most used magnitude values published in the catalogues of regional national centers. The kind of magnitude for a few of events in Greek and Turkish territory is not shown. For our hazard purposes, in the cases of absence of M_S and m_b estimations we use namely national M_d or M_L determinations as a relevant value for evaluation of the relatively small events in the respectively neighbour country.

The analysis of the main initial catalogue [7] with some revisions shows that information about historical seismicity in Bulgaria and the vicinities is very incomplete. Only a few moderate earthquakes with magnitude $M < 5.0$ are observed before 1892 (the starting point of organized macroseismic observations in Bulgaria). According to the literature sources the parameters of the historical earthquakes are determined from available macroseismic data. The accuracy of the earthquake parameters determination is usually as follows: origin time–from 15 minutes to an hour; coordinates–from 0.3 to 0.5 degree; depth–from 5 to 20 km for shallow and about 30 for intermediate events; maximum intensity–from 0.5 to1 degree MSK; magnitude–from 0.3 to 0.5 unit, based on $M(I_0)$ relations.

A seismometric station is built in town of Sofia at the beginning of the 20th century in order to contribute the more accurate collection of data for the Bulgaria territory. Unfortunately, the national network for instrumental localization of the earthquakes has begun its formation in 60 s–this is the starting point of the "modern instrumental" period in the development of the seismological observation in Bulgaria [15]. As a rule, before this time, the weak earthquakes only with magnitude $M > 4$ are well macroseismically documented for accurate (under the limitations of the macroseismic method) hypocenter determination.

Higher reliability and homogeneity of the hypocenter localization of the weak earthquakes ($M \geq 3.0$) in all over the country and adjacent territory is created in the 70s, when at least several seismological stations started to operate in Bulgaria as well as in the neighbouring countries. The namely moderate National telemetric networks in Bulgaria, Greece, Romania and Turkey have been formed in very short periods around 1980. Today, after some experimental periods, a reliability localization of the microearthquakes with magnitude $M > 1.5$ is provided for nearly the whole Bulgarian territory [10].

Generalizing the above information about the "instrumental" period we could conclude that the macroseismic data are predominant in the process of estimation of earthquake parameters for the period 1900–1940, the instrumental–for the period 1940–1970, and for the period after 1970–only instrumental data are used. The determination accuracy for the last period is: origin time–from 0.1 to 1 sec; coordinates–from 0.02 to 0.2 degree; depth–from 1 to 10 km; maximal intensity–0.5 degree MSK; magnitude–from 0.1 to 0.3 unit.

4. FINAL UNIFIED CATALOGUE WITH HOMOGENEITY M_S MAGNITUDE ASSESMENT

To make the catalogue useful for hazard estimations the authors performed some transformations to achieve the value of a reference magnitude for each event in homogeneity form. It was decided to choose M_S magnitude as a widely used assessment in our source catalogues. For the period 479 BC–AD 1977 on the territory of Bulgaria and the close surrounding areas all magnitudes are presented in M_S [7]. For the same territory during the period 1978–2003 the magnitude M_d of NOTSSI determinations is calibrated towards the magnitude M_S. For the others periphery situated territories correlations between the magnitudes M_S and m_b and M_S and M_L are worked out, using the earthquake analysis software SEISAN [13]. For lack of sufficiently simultaneous determinations for the magnitudes M_S and M_d no correlation is obtained.

For working out a relation between M_S and M_L 74 events from the seismological stations Athens, Thessalonica and ISC are used. The Fig.1 presents the graph of the correlation between the two types of magnitude. The linear approximation of the data is determined as follows:

$$M_S = 1.591\ Ml - 2.729.$$

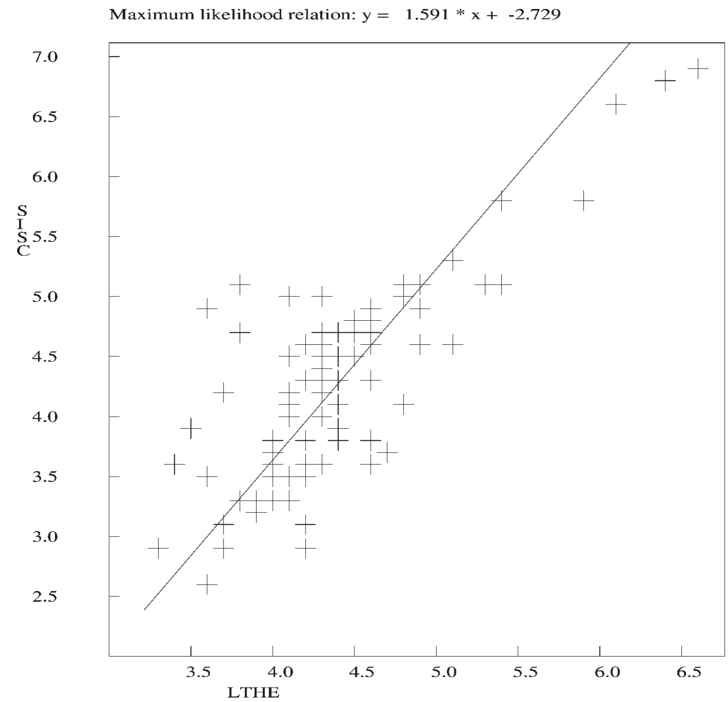

Fig. 1. Relation between M_S and M_L (SISC–M_S from the ISC catalogue; LTHE–M_L from the stations Thessalonica and Athens)

For determining the correlation between the magnitudes M_S and m_b are used 157 events with magnitude M_S and m_b from ISC. Fig. 2 represents the graph of the correlation between the respective magnitudes. The following linear correlation is determined:

$$M_S = 1.684\ mb - 3.455.$$

Since the above specified local correlations appeared to be more precise than the correlations of Guttenberg-Richter and Bott for the considered territory, they are used for translation of the magnitudes M_L and m_b towards magnitude M_S. Homogenized catalogue for the period 479 BC–AD 2003 contains total number of events 10311. The constituted catalogue is separated into main events and aftershocks data. For the territory of Bulgaria and the close

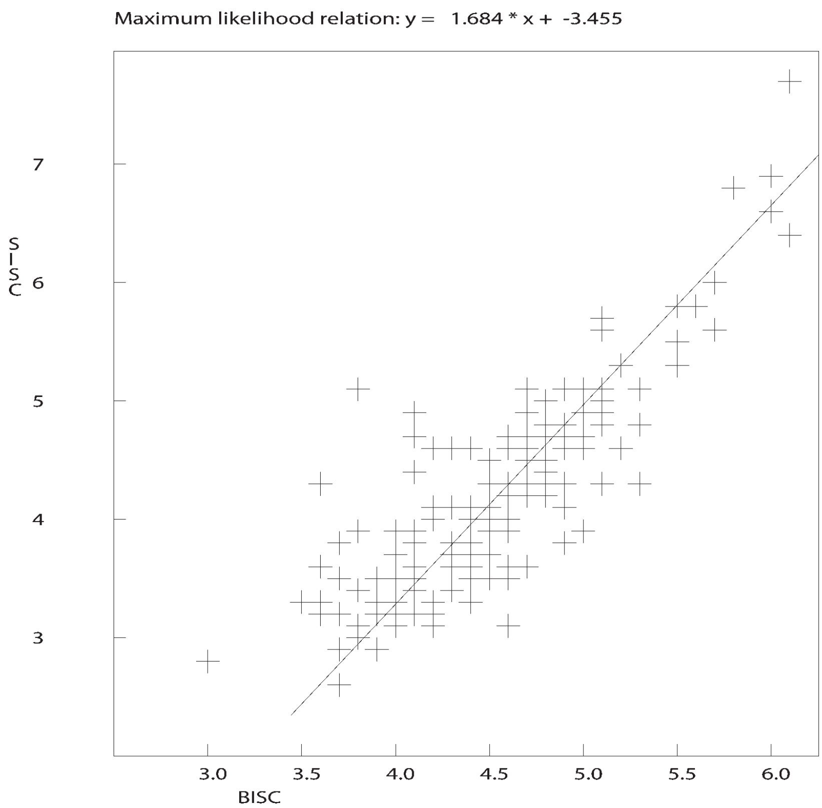

Fig. 2. Relation between M_S and m_b (SISC–M_S from the ISC catalogue; BISC–m_b from the ISC catalogue)

surrounding areas, the window of Christoskov-Lazarov [16] had been used, according to the procedure of preparation of the catalogue in [7]. For the others periphery situated territories, the window of Knopoff [17] is used. So, our final catalogue without aftershocks contains 6160 in number independent event. From them with $M < 3.0$ are 1701; $3.0 \le M < 4.0$–3497; $4.0 \le M < 5.0$–602; $5.0 \le M < 6.0$–208; $6.0 \le M < 7.0$–93; $7.0 \le M < 8.0$–59.

The catalogue, containing only the main events, is tested for completeness, using the earthquake analysis software SEISAN for periods with different continuation and different magnitude intervals. The magnitude distributions for many different time intervals are investigated. It is obvious that at the end of the catalogue the completeness of the smaller events increases. For example the magnitude distributions for one of the 20th century initial time interval (1900–1920) is presented on Fig. 3. From the investigated distributions various levels of completeness are obtained, for example, magnitude level $M = 5.0$ since the year 1700 and magnitude level $M = 3.7$ since the year 1900.

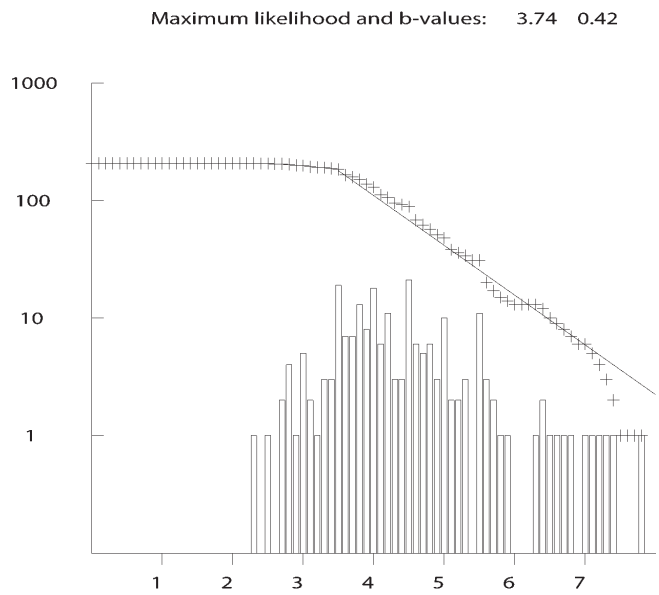

Fig. 3. Magnitude distribution for determination of the completeness during the period 1900–1920

5. EPICENTRAL DISTRIBUTION OF THE DATA FROM THE FINAL UNIFIED CATALOGUE

A map of the earthquakes with the magnitude $M \geq 3.7$ for both historical and instrumental investigated period from1700 to 2003 is constructed on the basis of the data from the finally prepared catalogue file with homogenized magnitude assessment for M_S (Fig.4). On this map the dimension of the symbols of the epicenter locations is proportional to the magnitude M_S. The epicenters of the earthquakes are subdivided and marked into two classes in function of their location accuracy: for the period 1900–2003–with the circles and for the historical period (exclusively macroseismical determination of the epicenters)–with triangles. The largest symbols refer to earthquakes with magnitude greater than or equal to 7.0 and the smallest–to events with magnitude greater than or equal to 3.7 and smaller than 4.0. In such way information for the epicentral distribution of about 1236 earthquakes is presented on this figure.

From the picture of the distribution of the earthquakes on the Bulgarian territory some grouping of epicenters can be observed. First of all, this grouping confirms tectonic activity of the lands on the Souh-Western part.

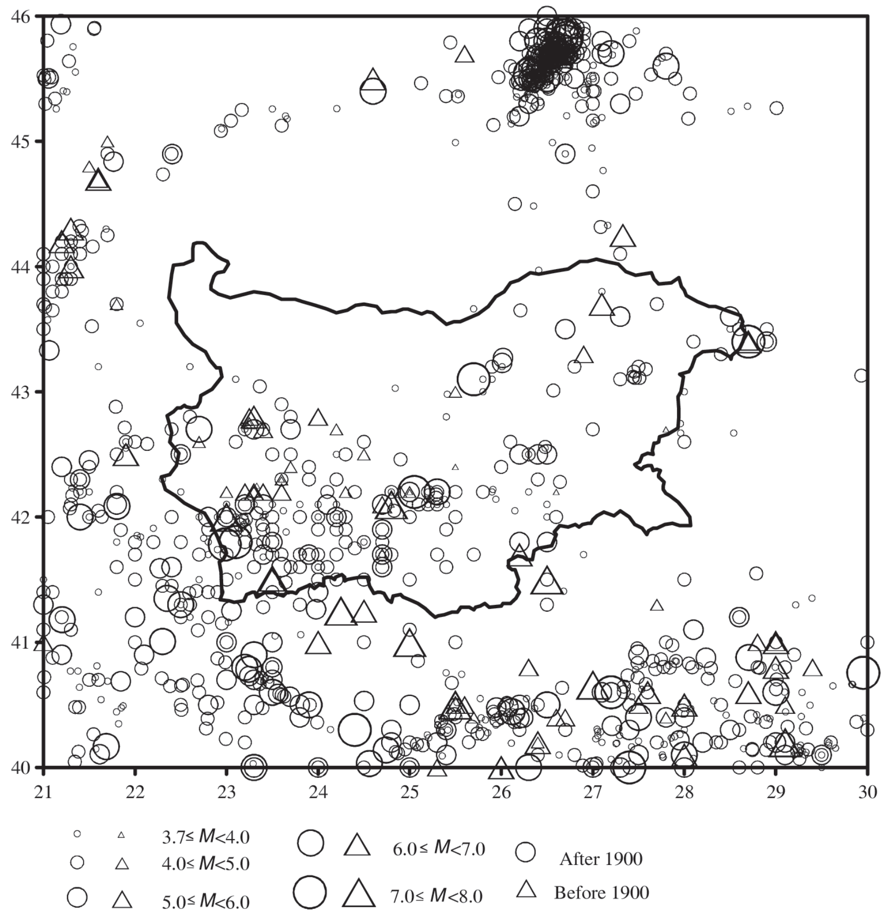

Fig. 4. Epicentral map for the earthquake with M > 3.7 during the period 1700–2003

The central part, as well as the North-Eastern part of the examined territory are caracterized with some lower activity. As a whole, a grouping of the earthquakes around the strongest sources is observed. The hypocenters of the earthquakes are concentrated in the surficial 10–20 km level, with only a few events of greater depth.

The strongest event in the country (Struma zone) is the earthquake of April 4, 1904 with a magnitude M = 7.8 followed by an aftershock sequence that lasted till the beginning of the 1907 and is preceded by a six-months foreshock sequence. An earthquake with magnitude M = 7.3 occurred in almost the same place, 20 minutes before the main shock. In 1901 the one M = 7.2 event occurred in the northern part of the Black sea cost. One strong earthquake with magnitude $M = 7.0$ took place in 1913 in the region of Gorna Oryahovitza on the periphery of the Fore-Balkan and Moesian platform in the Central North Bulgaria. The last big earthquake with magnitude $M = 7.1$ occurred in Central South Bulgaria in 1928. It is remarkable that there are no events with $M > 6.0$, and only several events with $5.0 < M < 6$, after 1928. After the relatively high frequency of the moderate events until 1940, there is less activity during recent years, when high magnitude events are especially missing. Only two earthquakes with magnitude $M = 5.5$ and $M = 5.7$ (with long aftershocks sequences) occurred during 1986 in the region of Strazhitza (Central North Bulgaria).

From the picture of the epicentral distribution it is obvious that the seismicity before 1900 shows almost the same distribution of the earthquakes. Many destructive earthquakes occurred in the past, mainly in Southern and North-Eastern Bulgaria. The exception is towards the South-Easthern part – one very strong historical earthquakes were observed in the region of Edirne (nearby the border point of Bulgaria, Greece and Turkey), which does not demonstrate strong activity during the 20th century. In the South-Eastern edge of the region of investigation, the majority of shallow earthquakes aggregate in a belt parallel to Marmara sea, which extends to the West in the North Aegean sea shelf belt. The territory of Northern Greece is affected by very strong sequence with $M_{max} = 7.0$ during 1932. One year before that a catastrophic event with magnitude $M = 6.7$ stroked Southern Macedonia. Except Vrancea zone all other zones generate only shallow earthquakes predominantly in a layer $h = 5–20$ km. The earthquakes in the Vrancea zone are mainly generated in the depth interval $h = 90–150$ km. This is the most distant zone to the territory of Bulgaria, but because of the deepest strong seismic activity, it produces the strongest makroseismic effects on the northern periphery of the Bulgarian territory (125 killed in town of Svishtov after the $M = 7.2$ earthquake during 1977). The seismic activity out of the determined seismogenic zones is lower as a rule, and it is connected mostly with some known fault structures. The strongest earthquakes generated out of defined zones are, for instance, one northern Greece event ($M = 7.2$, 1829), and Dulovo event ($M = 6.6$, 1892). Some aseismic zones could be recognized, for instance, in the western part of the stable Moesian platform, and in the southern part of the Black sea cost.

6. CONCLUSION

As a whole the results obtained during the preparation of the catalogue of earthquakes in the central part of the Balkans for a seismic hazard assessment by the method of spatially smoothed seismicity proposed by Frankel show some new specific characteristics. First of all is the fact that the preliminary catalogue contains all the available information about the events with $M \geq 2.9$ not only for Bulgaria but for the much more larger territory with the corner coordinates 40^0 N, 21^0 E–46^0 N, 30^0 E. This new catalogue is coordinated not only with the both highly integrated main catalogues [7] and the last version of Regional catalog of earthquakes of ISC, but as well as with the national catalogues of the neighbour countries. As a result a catalogue with 10311 earthquakes with minimum magnitude $M \geq 2.9$ is compiled for the period 479 BC–AD 2003. The new original relations obtained for the conversation of the various magnitude determinations into M_S show the maximum reliability for events with M_L and m_b initial magnitudes. The subsequent separation of the independent main events from all data shows 6160 main events. For the last events various levels of completeness for different time periods are obtained. The catalogue is complete, for example: since 1700 – for magnitudes $M \geq 5.0$; since 1900 – for magnitudes M ≥ 3.7; since 1970 – for magnitudes $M \geq 3.0$. Because of this it is advisable to use the catalogue since 1700 for the seismic hazard assessment by means of the method of spatially smoothed seismicity. The number of main events with $M \geq 3.7$ is for the period 1700–2003 is 1236. As a whole the catalogue data show significant coincidence between the epicentral distribution of the historical and recent events.

REFFERENCES

1. Frankel, A. *Seismological Research Letters*, **66**, 4, 1995, 8.
2. McGuire, K. R. *Annali di Geofisika*, **36**, 3–4; 1993,181.
3. Cornell, C. A. *Bulletin of Seismological Society of America*, **58**, 5, 1968, 1583.
4. Frankel, A., Mueller, Charles, Barnhard, Theodore, Perkins, David, Leyendecker, E.V., Dickman, Nancy, Hanson, Stanley, and Hopper, Margaret, 1996, Documentation: U.S.Geological Survey, 1996, ttp://eqhazmaps.usgs.gov/hazmapsdoc/junecover.html
5. Lapajne, J. K., B. S. Motnikar, B. Zabukovec and P. Zupancic. http://www.sigov.si/ugf/ang/hazard/doc1.html
6. Lapajne, J. K., B. S. Motnikar, B. Zabukovec and P. Zupancic. *Journal of seismology,* **1**, 1,1997, 73.
7. Христосков, Л., Е. Григорова, С. Рижикова, Д. Сокерова. Каталог на българските земетресения, ГФИ, БАН, Sofia, 1981.
8. Bonchev, E.,V. I. Bune, L. Chistoskov, J. Karagjuleva, V. Kostadinov, G. I. Reisner, S. Rizhikova, N. V. Shebalin, V. N. Sholpo, D Sokerova. *Geologica Balcanica*, **12**. 2,1982, 27.
9. Solakov, D., S. Simeonova (ed.). Bulgaria catalog of earthquakes 1981–1990. BAS, Sofia, 1993.
10. Botev et all. *Bulg.Geophis.J.*, **17–29**, 1991–2003.
11. Shebalin, N., V. Karnik and D. Hadzievski. Catalogue of earthquakes, UNDP/UNESCO Survey of Seismicity of the Balkan Region, Skopie, 1974.

12. Comnikas, P. E., B.C. Papazachos. A catalogue of earthquakes in Greece and the surrounding area for the period 1901–1985. University of Thessaloniki, 1986.
13. Ergin, K., U. Guclu, Z. Uz. A Catalog of Earthquake for Turkey and Surrounding Area for the Period 11–1964. Istambul, 1967.
14. http://www.isc.ac.uk/
15. Христосков, Л. *Българско геофизично списание*, **XVIII**, 1, 1992, 3.
16. Христосков, Л., Р. Лазаров. *Българско геофизично списание*,**VII,** 3, 1981, 58.
17. Gardner, J., L. Knopoff. *Bull.Seis.Soc.Am.*, **64**, N5, 1974, 1363.

Received November 2005

Minka Ilieva
St. Kliment Ohridski University of Sofia
Faculty of Physics
Department of Meteorology and Geophysics
5, James Bourchier Blvd.
1164 Sofia, Bulgaria
E-mail: ilieva@phys.uni-sofia.bg