CONTRIBUTION TO THE ESTIMATION OF SEISMIC HAZARD IN BANAT REGION (ROMANIA)

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Located in the southwestern of Romania, the Banat region is characterised by a relevant seismic activity. So, the last century, 28 earthquakes with $M \geq 4.1$ ($I_0 \geq VI$) were identified. The strongest earthquakes ($M=5.7$, 5.6, 5.6) occurred in the second part of 1991, the last year of the highest observed seismicity. The events have a shallow depth. The correlation of the earthquake foci with local tectonics is remarkable. To estimate the seismic hazard in the Banat region was used the theory of the largest values (G^I and G^{III} distribution) and Cornell's method. The characteristic parameters of Gumbel's distribution for two time intervals (1901–1993; 1871–1993; $M \geq 4.1/I_0 \geq VI$) are computed. The values obtained (in terms of M and I_0; the time interval of sampling being 10 years) are very close. One notice the values obtained for G^I: b = 0.95, u = 4.6, T(6.0) = 210 years; $M_{max}(P=1\%) = 5.7$; $M_{max}(P=0.5\%) = 6.0$. The last value is very close to $M_{max}=6.3$, obtained by the application of G^{III} distribution. The difference $\delta M = M_{max}–M_{obs} = 0.6$ is acceptable. The seismic hazard is expressed by the exceedance of the probability of some parameters (M, I_0, a) in a certain period. The use of Cornell's method allows to draw-up the iso-acceleration contours for diferent periods. The quantitative study of the Banat region seismicity confirms its high seismic potential and the necessity to adopt real measures for the antiseismic protection in this area.

Key words: Seismotectonic, earthquakes, probabilistic analysis, seismic hazard, iso-accelerograms and iso-intensities maps, return period, Banat.

1. INTRODUCTION

The Banat region located in the south-western part of Romania (Fig. 1) is characterized by a relevant seismic activity. During the 1794–1993 period, 43 earthquakes with $M \geq 4.1$ ($I_0 \geq VI$) were identified (Table 1), but the strongest events (M_s = 5.7, 5.6, 5.6) occurred during the last years. The second part of 1991 was the period of the highest observed seismicity in the Banat region. The events have a shallow focus (maximum 25 km, minimum 4 km) and are associated with aftershocks and/or foreshocks. The correlation of the earthquake focus with the local tectonics is remarkable.

Table 1

Catalogue of Banat earthquakes ($M \geq 4.1$) during 1794–1993 (Radu, 1994)

No	Date	Time (GMT) h:m:s	Lat. N^0	Long. E^0	H Focus Depth km	I_0 Epicentral intensity	M^D Gutenberg-Richter magnitude
1	1794 Oct.19	09:00	46.2	21.3	10	VII	4.7
2	1847 Oct.15	06:15	46.2	21.3	10	VII	4.7
3	1859 Oct.17	09:30	46.1	20.9	10	VII	4.7
4	1879 Oct.10	15:45	44.7	21.7	7	VIII	5.3
5	1879 Oct.11	02:45	44.7	21.7	10	VII	4.7
6	1879 Oct.17	02:53	44.7	21.7	10	VI	4.1
7	1879 Oct.20	10:45	44.7	21.7	10	VI	4.1
8	1879 Oct.31	18:30	46.1	20.7	10	VII	4.7
9	1879 Nov.1	06:30	46.1	20.7	10	VI–VII	4.5
10	1879 Nov.19	23:10	45.7	21.2	10	VI	4.1
11	1879 Dec.22	04:03	44.7	21.7	10	VI	4.1

Rev. Roum. GÉOPHYSIQUE, **52–53**, p. 11–18, 2008–2009, Bucureşti

Table 1 (continued)

12	1880 Apr.13	11:20	44.7	21.7	10	VI	4.1
13	1887 Jul.10	02:56	46.0	21.2	10	VI	4.1
14	1894 Dec.19	21:30	45.0	21.7	8	VII	4.7
15	1900 Jan.29	01:15	46.0	21.2	8	VII	4.7
16	1901 Apr.02	16:55	45.5	20.75	18	VII	5.0
17	1902 Jan.21	12:46	45.8	21.5	5	VI	4.1
18	1903 Jul.20	10:40	45.5	21.1	6	VI	4.1
19	1909 Aug.31	21:21	45.1	21.9	20	VI	4.4
20	1910 Oct.11	11:52	44.9	22.4	7	VI	4.3
21	1912 Apr.16	04:30	45.2	21.9	10	VI	4.1
22	1915 Oct.09	21:30:29	45.4	21.1	4	VI–VII	4.4
23	1915 Oct.19	08:30:09	45.4	21.1	5	VII	4.8
24	1915 Oct.27	–	45.4	21.1	(5)	VI	4.1
25	1927 May31	22:58:15	44.9	21.7	10	VI	4.4
26	1936 Sep.06	04:49:02	45.7	21.1	10	VII	4.8
27	1938 Jul.08	06:32:49	46.0	20.7	6	VI–VII	4.3
28	1941 Aug.30	04:41:44	45.7	20.85	7	VII	4.8
29	1956 Oct.01	23:23	45.4	21.1	4	VI	4.1
30	1957 Sep.22	14:44	45.6	21.1	4	VI	4.1
31	1959 May29	20:38:28	45.65	21.2	5	VII–VIII	5.0
32	1960 Oct.22	19:17:48	45.6	21.1	12	VI	4.1
33	1973 Aug.23	14:52:43	45.71	21.15	25	VI	4.2
34	1974 Apr.17	01:31:34	46.0	21.1	20	VI	4.1
35	1978 Jan.17	02:29:33	45.77	21.06	15	VI	4.1
36	1991 Jul.12	10:42:21	45.38	21.05	11	VIII	5.7
37	1991 Jul.18	11:56:31	44.90	22.35	12	VIII	5.6
38	1991 Jul.19	01:27:32	45.31	21.05	10	VII	4.8
39	1991 Aug.12	04:59;39	45.47	21.15	14	VI	4.2
40	1991 Aug.14	23:36:03	45.32	21.22	10	VII	4.6
41	1991 Dec.02	08:49:41	45.45	21.12	9	VIII	5.6
42	1991 Dec.19	03:12:22	45.91	21.57	10	VI	4.1
43	1993 Dec.19	09:34:06	45.64	20.94	16	VII	4.1

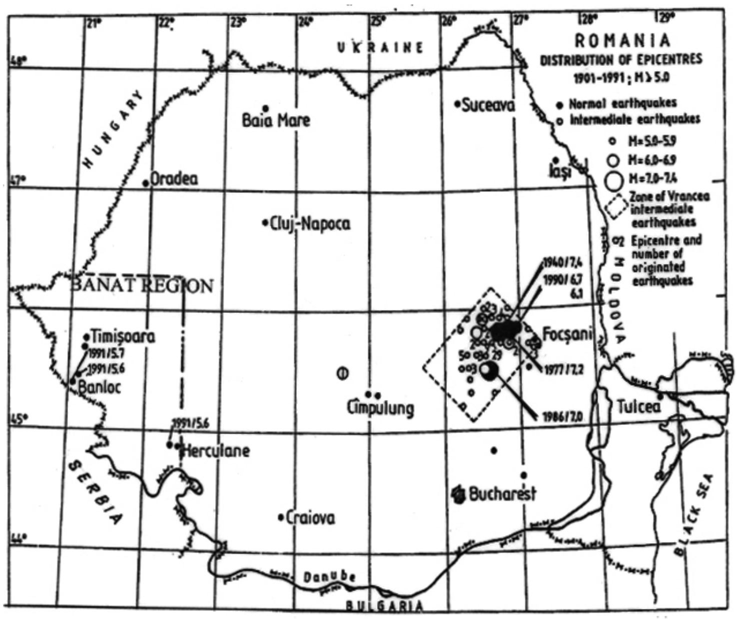

Fig. 1 – Epicenters of the earthquakes (M≥5, 1901–1991).

The paper is based on the synthesis of many previous specific studies and applications (Moldoveanu, Radu, 1995; Moldoveanu, 1998, 2002) and presents the authors contributions to the completion and implementation of a methodology (Moldoveanu *et al.*, 2004–2007), used to elaborate specific *Site Seismic Studies – SSS* for dams, as well as to justify and optimize the data, necessary to structural computations. Such applications were recently (Moldoveanu *et al.*, 2004–2007) performed, to update the SSS and structural seismic safety verification for concrete arch dams in the area, such as Herculane (H = 58.50 m), Poiana Ruscă (75 m), Clocotiş (56 m); dynamic characteristics calculated with the SSS data, obtained according to the mentioned methodology, were confirmed by *in situ* studies and vibrations measurements (Moldoveanu *et al.*, 2004–2007).

2. SEISMOTECTONIC CONDITIONS

The seismotectonic studies carried out for the Banat seismic area, pointed out the neotectonic activity implications of the area on the regional and local seismicity, the relation between the tectonic structure and the history of the tectonic movements which finalized the present ensembles, geotectonics and the distribution of the recorded local earthquake epicenters. The seismotectonic map of the Banat area (Fig. 2) shows a remarkable correlation between earthquake foci and tectonics, the presently active faults respectively. Before 1990, the Banat area was classified, according to the Romanian standard of seismic zonation (STAS 11100/1–93), most of it being the 6 degree macrozone of seismic intensity and a small part, the 7 degree macrozone. As a result of the strong earthquakes produced in the Banat zone, nearby Banloc (12.07.1991; M_s = 5.7; I_0 = VIII MSK), Herculane (19.07.1991; M_s = 5.6; I_0 = VIII MSK) and Voiteg (02.12.1991; M_s = 5.6; I_0 = VIII MSK), (Fig. 1), the STAS 11100/1–93 was replaced by the new SR 11100/1–93 seismic zonation standard (Fig. 3).

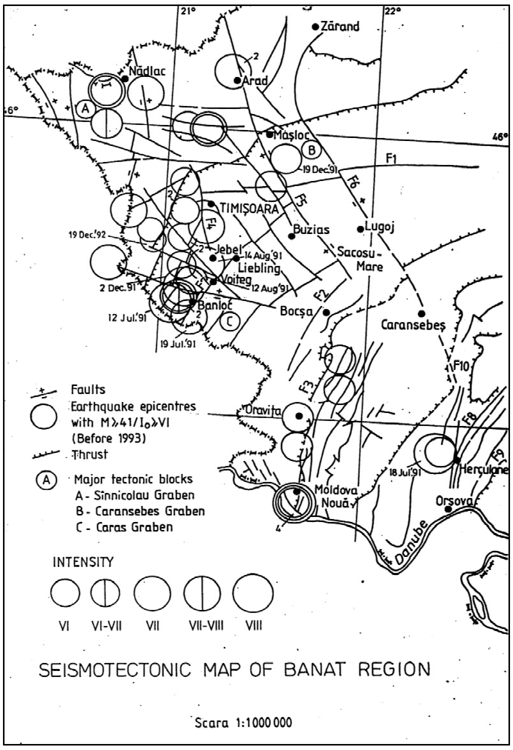

Fig. 2 – Seismotectonic map.

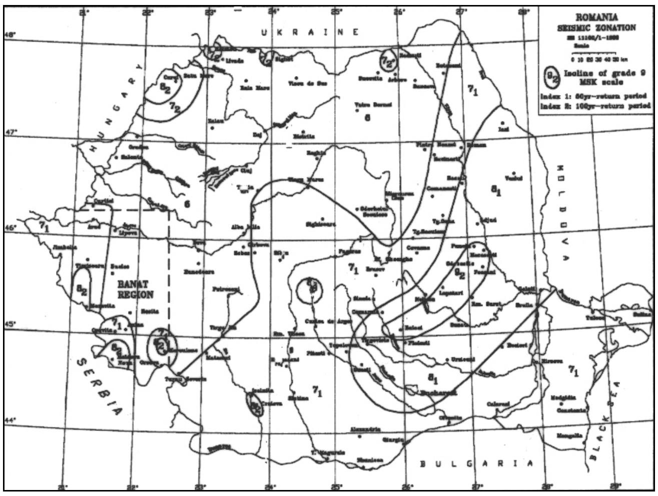

Fig. 3 – Seismic zonation (SR 11100/1–1993).

3. SEISMIC HAZARD ESTIMATION FOR THE BANAT AREA

For the seismic hazard estimation of the Banat area were used the statistical-probability procedures and methods: frequency-magnitude relation, the extreme values method (Gumbel I and III distributions), the Cornell-Vanmarcke (1980) method.

For the frequency-magnitude relation determination there were used the expressions:

a. Gutenberg-Richter relation (1956):

$$\log n(\geq M) = a - bM \tag{1}$$

By using the data from Table 1, the following relation was obtained:

$$\log(N_c / year) = 2.21 - 0.68M \tag{2}$$

The graphic representation is shown in Figure 4.

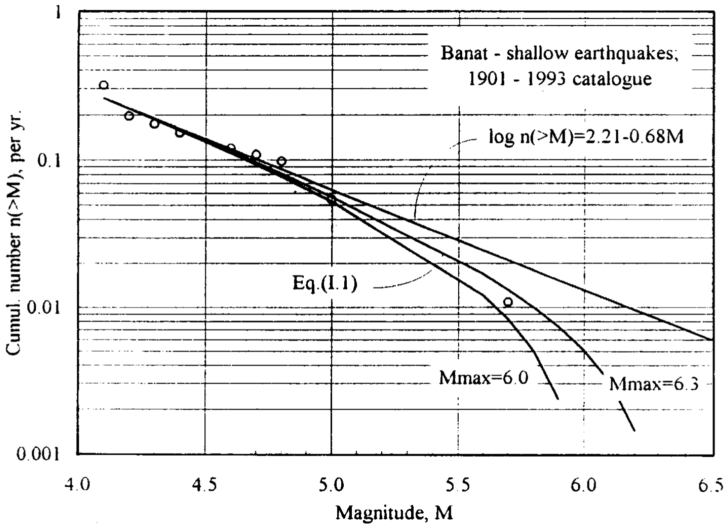

Fig. 4 – Magnitude recurrence relation for the Banat seismic region.

b. The Hwang and Huo (1984) modification into the Gutenberg-Richter relationship is:

$$n(\geq M) = e^{5.093-1.571M}(1 - e^{-1.571(M_{\max}-M)})/(1 - e^{-1.571(M_{\max}-4.1)}) \tag{3}$$

when the threshold magnitude is selected $M_0 = 4.1$, $\alpha = 2.2118\ln 10 = 5.093$ and $\beta = 0.682\ln 10 = 1.571$. The graphic representation of Hwang and Huo relation is presented in Figure 4.

The maximum credible magnitudes estimated for the Banat seismogenic region is $M_{max} = 6.0–6.3$ (Moldoveanu, 1996). For $M_{max} = 6.3$, the magnitude of the Banat earthquakes with 50, 100 and 475 years mean return period are: M = 5.5, M = 5.8 and M = 6.1–6.2.

To estimate the seismic hazard in the Banat region the theory of the largest values Gumbel's distribution was used:

$$G^I(m) = \exp\{-\exp[-\alpha(m-u)]\} \tag{4}$$

$$G^{III}(m) = \exp\{-[(\omega - m)/(\omega - u)]^k\} \tag{5}$$

The characteristic parameters of Gumbel's distribution for two time intervals (1901–1993; 1871–1993; $M \geq 4.1/I_0 \geq VI$) are computed. The values obtained (in terms of M and I_0; time interval of sampling is

10 years) are very close. One notices the values obtained for G^I distribution: b = 0.95, u = 4.6, T(6.0 = 210 years, $M_{max}(P=1\%) = 5.7$; $M_{max} = 6.3$, obtained by applying the G^{III} distribution. The difference $\delta M = M_{max} - M_{obs} = 0.6$ is acceptable. The graphic representation obtained through the application of Gumbel I and III distribution for magnitude (M_s) and the epicenter intensity (I_0) are presented in Figures 5 and 6.

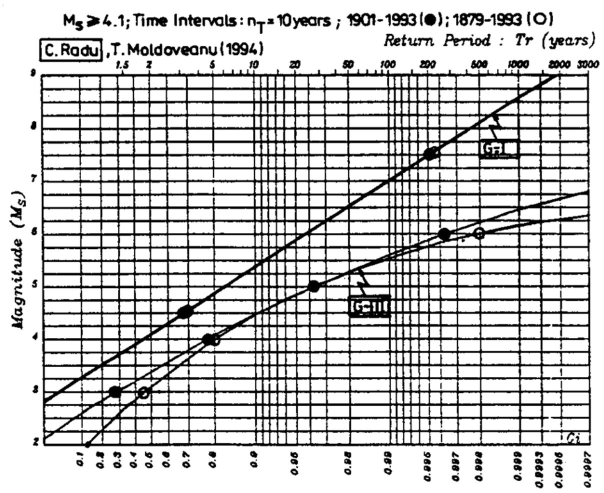

Fig. 5 – Banat seismic region (Ms ≥ 4.1).

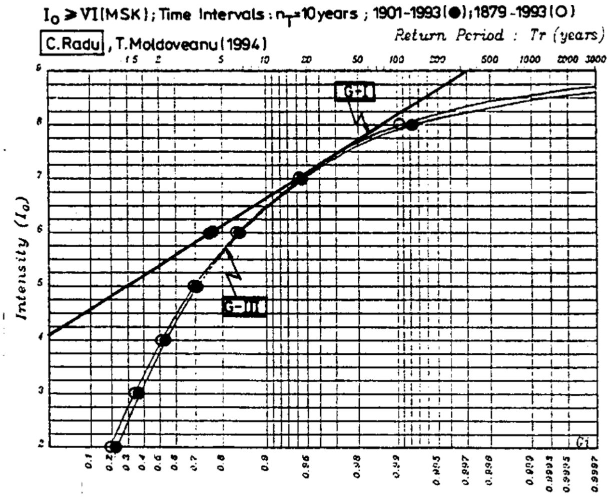

Fig. 6 – Banat seismic region (Io ≥ VI (MSK).

For the application of the Cornell–Vanmarcke (1980) method the following data and hypotheses were considered: the model source – line (fault); the existence of eight sources – lines (faults) (Fig. 2); the attenuation relation of acceleration: horizontal (a_H), established by Macropoulos and Barton (1985, Eq. 6) and Stamatovska and Petrovski (1991, Eq. 7), respectively:

$$a_H = 2164 e^{0.7 M_s} (R_h + 20)^{-1.8} [cm/s^2] \quad (6)$$

$$a_H = 534.355 e^{0.4608 M_s} (R_h + 25)^{-1.14459} [cm/s^2] \quad (7)$$

The use of Cornell's method allows draw-up the iso-acceleration contours for different return periods. In Figures 7, 8 and 9 there are presented the iso-acceleration contours maps for the return periods of 50, 100 and 475 years. In Figures 10, 11 and 12 there are presented the iso-intensity contours maps for the return periods of 50, 100 and 200 years, both kinds of maps for the first time so detailed in Romania.

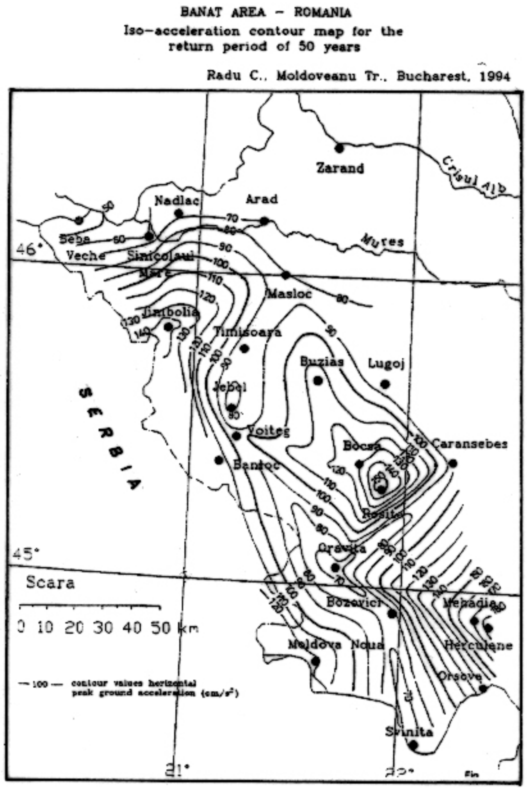

Fig. 7

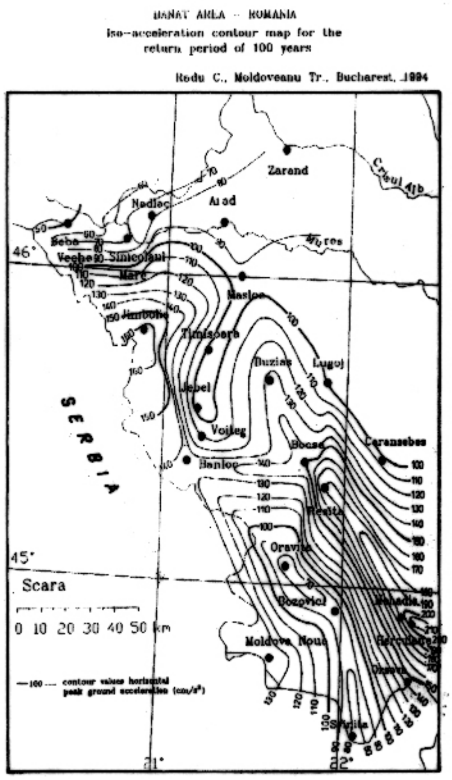

Fig. 8

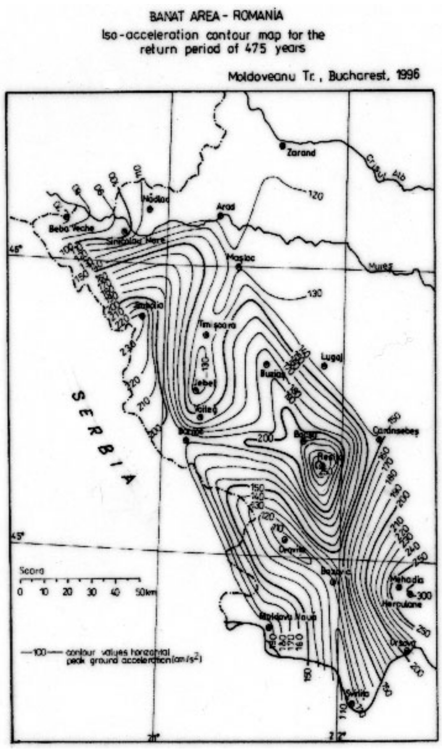

Fig. 9

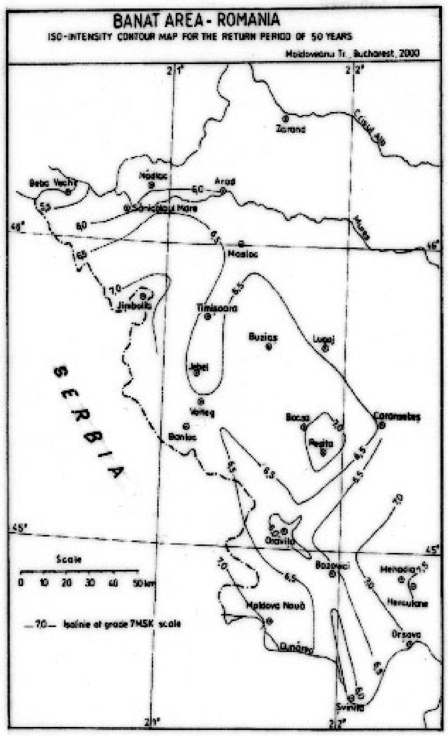

Fig. 10

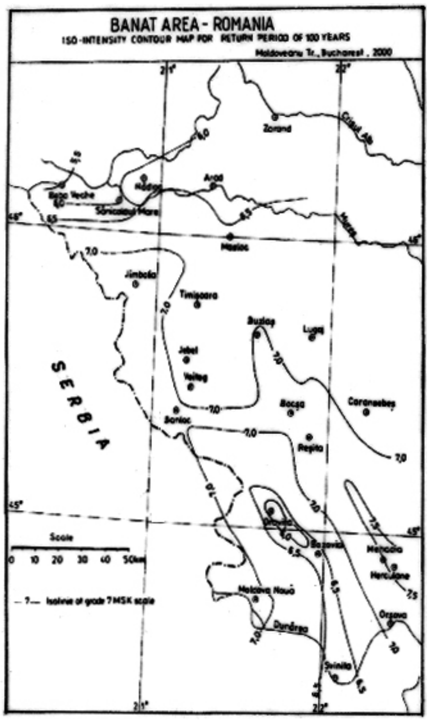

Fig. 11

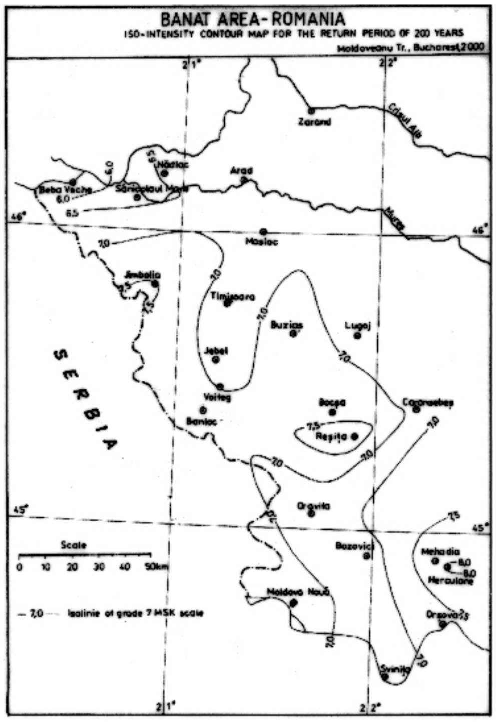

Fig. 12

4. CONCLUSIONS

The Banat area, located in the south-west Romania, is characterized by an important seismic activity significantly pointed out in the last ten years (for example 1991). The estimation synthesis of the seismic hazard for this area is distinguished by the maps with iso-accelerations (Figures 7, 8 and 9) and iso-intensities (Figures 10, 11 and 12). The iso-intensity maps presented in Figures 10, 11 and 12 represent a proposal for the Banat area seismic zonation. The quantitative study of the seismicity of the Banat region confirms its high seismic potential and the necessity to adopt real measures for the antiseismic protection in the area.

The paper represents the authors experience based on many specific studies and applications and presents their contributions to the completion and implementation of the mentioned methodology (Moldoveanu *et al.*, 2004–2007), used to elaborate the *Site Seismic Studies-SSS* for dams, establishing the specific data, necessary to structural seismic behaviour analysis. In this context, were represented, the first time in Romania, area izoseists distributions for IMR = 100, 450, 800 years (*e.g.* Figures 2, 8, 9), a really useful instrument in establishing and interpreting seismic data for structural computations.

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Received: November 19, 2008
Accepted for publication: February 28, 2009