MACROSEISMIC INTENSITY DISTRIBUTION OF SOME RECENT ROMANIAN EARTHQUAKES

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Between years 2001 and 2004 a number of earthquakes with magnitudes which ranged from 3.9 to 5.0 occurred in the most seismically active areas of the Romanian territory. A macroseismic analysis of the effects produced on the Romanian territory has been conducted for these earthquakes, by using macroseismic questionnaires. Some of the observed intensities were significantly higher than those we could have expected after the earthquakes with such magnitudes. Effects have been evaluated from macroseismic observations giving maximum intensities estimated as VI–VII and VII in the MSK scale, respectively. Given the small to moderate size of earthquakes, many of the observed damages to buildings are due to their bad state, age, and poorly built without antiseismic protection, and hence particularly vulnerable.

Key words: macroseismic questionnaires, earthquake effects, isoseismal map.

1. INTRODUCTION

The macroseismic data are considerably used for the integration of the general viewing on the spatiotemporal evolution of the seismic intensity, for the purpose of hazard assessment in given areas or in special sites related to the national infrastructure. Nowadays, even if the seismological instrumental networks are very developed, the macroseismic maps with maximum intensities still remain an important tool for the anti-seismic design of constructions.

Seismic events occurring within the Romanian territory are recorded and immediately localized by the personnel on duty of the National Institute for Earth Physics (NIEP). Most of the Romanian territory is prone to earthquakes. During centuries, the earthquakes occurred in all Romanian seismogenic zones have caused severe damage and killed or injured thousands of people [2, 3, 13]. Only in the last century, two destructive earthquakes struck the territory of Romania: in October 11, 1940 and in March 4, 1977. The 1940 Vrancea earthquake reached intensity X MSK, and the earthquake of March 1977 occurred in the same region, reached intensity IX–X MSK [8, 9, 15].
In the same century, other three strong earthquakes were generated in Vrancea seismogenic zone, on August 30, 1986, May 30 and 31, 1990, but without casualties. In the studied period 2001–2004, an average of 250 earthquakes (Mw > 2) per year were recorded by the seismic stations of the national network [16].

The objective of this paper is represented by the macroseismic studies of a series of earthquakes with 3.9 ≤ M ≤ 5.0, occurred in Romania during 2001–2004. Our studies are based on the macroseismic questionnaires (MQs) that have been sent immediately after the events, in areas where these earthquakes were felt. The results have been obtained by processing, analysis and interpretation of existent information taken from MQs. Parameters of the earthquakes generated by Vrancea, Banat and Dobrudja seismogenic zones are presented in Table 1. The macroseismic analysis of these earthquakes in the same study was accomplished because they fulfill the following criteria: short time interval of occurrence, small to moderate magnitudes and the total number of macroseismic questionnaires filled in by the respondents and returned from the field.

### Table 1
Parameters of the analyzed earthquakes

<table>
<thead>
<tr>
<th>No.</th>
<th>Date (year, month, day)</th>
<th>Hour (UTC)</th>
<th>Zone</th>
<th>Lat.N</th>
<th>Long. E</th>
<th>h (km)</th>
<th>Mw</th>
<th>mb (ISC)</th>
<th>Io</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2001.05.24</td>
<td>17:34:02</td>
<td>Vrancea</td>
<td>45.63</td>
<td>26.42</td>
<td>143.7</td>
<td>4.9</td>
<td>4.8</td>
<td>V-VI</td>
<td>Romplus</td>
</tr>
<tr>
<td>2</td>
<td>2001.07.20</td>
<td>05:09:40</td>
<td>Vrancea</td>
<td>45.75</td>
<td>26.79</td>
<td>132.5</td>
<td>4.8</td>
<td>4.9</td>
<td>V-VI</td>
<td>Romplus</td>
</tr>
<tr>
<td>3</td>
<td>2002.05.24</td>
<td>20:42:28</td>
<td>Banat</td>
<td>44.84</td>
<td>21.77</td>
<td>10</td>
<td>3.8</td>
<td>4.7</td>
<td>VII</td>
<td>Romplus</td>
</tr>
<tr>
<td>4</td>
<td>2002.11.30</td>
<td>08:15:48</td>
<td>Vrancea</td>
<td>45.62</td>
<td>26.54</td>
<td>166.4</td>
<td>4.7</td>
<td>5.0</td>
<td>V-VI</td>
<td>Romplus</td>
</tr>
<tr>
<td>5</td>
<td>2004.09.27</td>
<td>09:16:22</td>
<td>Vrancea</td>
<td>45.70</td>
<td>26.45</td>
<td>166.1</td>
<td>4.6</td>
<td>4.8</td>
<td>V</td>
<td>Romplus</td>
</tr>
<tr>
<td>6</td>
<td>2004.10.03</td>
<td>09:02:02</td>
<td>Dobrudja</td>
<td>45.18</td>
<td>28.94</td>
<td>7.6</td>
<td>—</td>
<td>—</td>
<td>5.0</td>
<td>VI</td>
</tr>
</tbody>
</table>

### 2. CHARACTERISTICS OF THE ZONES WHICH GENERATED THE STUDIED EARTHQUAKES

As already known, besides the Vrancea subcrustal earthquakes which are of great importance when considering the seismicity of Romania, a high contribution also have earthquakes generated by crustal seismic sources, such as Fagaras, Banat, Crisana-Maramures, Dobrudja, with high intensities around the epicenters (Table 1 and Figure 1). Generally, the intensities of crustal earthquakes from Romania did not exceed the intensity of VIII. The distribution of earthquakes epicenters with Mw ≥ 3 generated by Vrancea, Banat and Dobrudja zones and the epicenters of the studied earthquakes are displayed on the map in Figure 1.
From energetic point of view, the Vrancea seismogenic zone is the most important seismic zone from all Romanian territory, zone that generates two types of earthquakes, intermediate depth ones (60 < h < 200 km) and normal depth ones (h < 60km). It is well known that Vrancea subcrustal earthquakes are responsible for the highest damages, generally spread over 50% of Romania’s territory, due to high energies released. The frequency of major subcrustal earthquakes (destructive) occurrence is lower (3–4 per century), comparing to other zones with high seismicity in the world, but Vrancea subcrustal earthquakes with small to moderate magnitudes have a higher frequency of occurrence [9].

Other particularities of the Vrancea seismogenic zone are: the existence of temporal evisi-irregularities in earthquakes occurrence; the appearance of main shocks in the form of double or multiple earthquakes; the constancy, at global scale, of foci in approximately the same volume; the occurrence of the local amplification of the seismic intensity at epicentral distances up to 200–300 km away; wide areas with macroseismic effects that sometimes overcome the borders of the country [4].
2.2. THE BANAT SEISMOGENIC ZONE

Earthquakes from Banat zone have a polikinetic character, with numerous late aftershocks, in case of strong seismic events [7]. A representative case for that it was the succession of shakes occurred between October 1879 and April 1880, from Moldova Noua, and also in the 20th century, the case of the earthquake close to Timisoara city, from 27th of May 1959, with M = 5 and shallow focus (5 km depth), followed by two aftershocks in 1960. Another earthquake has occurred on 1st of December 1991 (M = 5.5) and was followed by the aftershocks from 19th of December 1991 and 19th of December 1992. The two following significant events (I = VI MSK) were generated during the summer of 1995 and spring of 1996. In 2002 the Western part of Romania was shaken by two earthquakes occurred at 2 months one after the other one, both having their epicenter in Moldova Noua area (the first shock on 24th of May and the second one on 2nd of August). Some of these earthquakes are related to well known seismo-tectonic alignments. From this point of view, in Banat zone there are three active seismogenic zones, characterized by earthquakes with $M_w > 5$, but which did not exceed $M$ of 5.6. Other characteristics of these earthquakes refers to the shallow depth of the foci (not more than 10–15 km), and also to the reduced area of the observed macroseismic effects. According to some authors, it seems that in Banat seismogenic zone, reverse and strike-slip faulting are predominant [1, 10].

2.3. THE NORTH DOBRUDJA SEISMOGENIC ZONE

The North Dobrudja seismogenic zone belongs to the southern region of the Predobrogean Depression and respectively to the North Dobrogea Orogen and it is related to the Sf. Gheorghe major transcrustal fault. In this zone, the seismicity is moderate ($M_w \leq 5.3$) and it is grouped around this fault, mostly between 15–20 km depth [12]. The major strike-slip fault character is quite obvious for Sf. Gheorghe fault, in depth having the tendency to narrow [14].

As stated above, the Dobrudja seismogenic zone does not show a high seismic activity from earthquake’s frequency and released energies points of view, thus, we can remark that the seismic events in this area did not have, as far as we know, major effects. The seismic activity of Dobrudja zone is related to its location in the vicinity of the triple junction and the tectonics determined by the existence of the following active faults: Peceneaga – Camena, Trotus – Sf. Gheorghe and Palazu. Dobrudja zone is divided in three major geological units, oriented NW, with different tectonic evolutions. These units are: North Dobrudja, where the earthquake from 3rd of October 2004 occurred, Central Dobrudja or the green schists area and South Dobrudja [14].
3. INTENSITY ASSESSMENT AND MACROSEISMIC MAPS

After the occurrence of the intermediate and normal depth earthquakes from Vrancea zone (24.05.2001, 20.07.2001, 30.11.2002, and 27.09.2004), and also those from Banat (24.05.2002) and Dobrudja (03.10.2004) zones, MQs were sent in the areas where these earthquakes were felt. For this study, the macroseismic questionnaires were immediately sent, via mail.

In order to collect the macroseismic information observed after these six earthquakes, two types of questionnaires were used: type I (classic) currently used in Romania, and type II (American type of questionnaire), adapted to the Romanian specific earthquakes according to the Seismic Intensity Scale (STAS 3684-71).

The elaboration of the macroseismic maps involves a complex analysis and interpretation of the information from the filled in questionnaires, regarding the macroseismic effects observed in the field, immediately after the occurrence of these earthquakes. Still, there are a lot of problems caused by various factors: the defective mail service, description of the observed macroseismic effects; the preparedness degree and, obviously, the liability degree of people requested to answer on site, which are reflected in the responses (more or less relevant) provided in the macroseismic questionnaires. For earthquakes studied in this paper, all these factors have had a negative effect on the information, as follows: the reduced number of questionnaires returned from the field, the ambiguity of the responses from the questionnaires, confusions, etc.

However, the final result is given by the interpreter, the researcher who makes the interpretation of the macroseismic information extracted from the questionnaires, since he/she must have, besides seismological knowledge, a background in geophysics-geology, and also expertise in construction engineering, in order to properly assess the damages resulted from structures behaviour to the seismic shaking.

The strictness of such an activity, of evaluating the effects and assigning the macroseismic intensities are compensated by the high amount of useful information used for the anti-seismic design of constructions, in the areas affected by earthquakes. The seismic intensities thus evaluated, are valid for large areas, in comparison to the instrumental recordings which have a punctual character and which can be extrapolated only on reduced areas.

The evaluation of the macroseismic information was accomplished according to the Medvedev-Sponheuer-Karnik (MSK) seismic intensity scale [5, 19] being displayed as values of intensity. Hence, the seismic intensities obtained after the evaluation of the observations filled in the MQs for each earthquake, were used to construct macroseismic intensities maps and, are presented as follows:
3.1. THE 24 MAY, 2001 EARTHQUAKE

This earthquake has occurred at 20:34 local time, in Vrancea seismogenic zone, at approximately 144 km depth, had a magnitude $M_w = 4.9$ and the epicentral intensity of $I_0 = V$–VI MSK.

According to the American Agency, National Earthquake Information Center (NEIC), this earthquake was felt in Republic of Moldova, in Chisinau city, with $I = V$ MM. The same agency gave an intensity of IV (the Mercalli scale) for the city of Bucharest. As observed in the map from Figure 2, there is no information regarding the effects produced in Bucharest. For the study of this earthquake there were information only from 17 localities in Romania, obtained from 55 MQs, from which 22 were negative.

![Fig. 2 – Isoseismal map of the May 24, 2001 Vrancea subcrustal earthquake.](image)

After the interpretation and evaluation of the obtained dataset, the results show that the maximum observed intensity was recorded in Panciu city, Vrancea county, and in Buzau city, Buzau county, and was VI MSK. Generally, the macroseismic effects described in the MQs filled in for these locations and based
on which led to the intensity estimation, are as follows: “[…] many people were scared, some people who were moving lost their balance, in different buildings falling light objects was observed, few glass objects and dishes were broken, some unfixed objects (books and others) were tilted or/and felt from shelves”. There was a very small number of observations regarding minor damages of buildings, but their appearance due to the earthquake is doubtful, meaning that we do not have to exclude the existence of some cracks before the earthquake, considering the age of the buildings (build between 1940–1977), repaired by the owners of those buildings and reopened due to the earthquake. The farthest locations from where we have information regarding this earthquake are: Bals city, Olt county, to the South in Oltenita city, Calarasi county; to the North up to Roman city, Neamt county and to the East the shock was felt in Tulcea city, Tulcea county.

3.2. THE JULY 20, 2001 EARTHQUAKE

The intermediate depth earthquake from 20/07/2001 was generated at 8:10 local time, in Vrancea zone, with it’s epicenter located at 15 km SSE from Vrancioaia locality, having a magnitude $M_w=4.8$ and an epicentral intensity of $I_0=V$-$VI$.

Depending on the earthquake magnitude and the area where it was felt, a big number of questionnaires were sent, in order to have a real and clear image of the macroseismic field specific to each earthquake. For this earthquake we have obtained 31 intensity data points (IDPs) from all the positive MQs. From the total number of MQs only 14 were negative.

For this earthquake, NEIC reported an intensity of V (MM scale) for Cahul (Republic of Moldova) and IV (MM scale) for Izmail (Ukraine). The quake was also felt in Chisinau city, Republic of Moldova ($I=IV$). This earthquake was felt also in Bucharest, but despite all efforts, no information was received regarding the effects. The maximum observed intensity was VI on MSK scale and was assigned to two localities: Patarlagele (Buzau) situated at 56 km from the epicenter, and Tichilesti (Braila) situated at 111 km (Figure 3a). In this case, there were similar effects as those generated by the earthquake from 24$^{th}$ of May 2001. In few situations, some cracks in buildings walls were reported still, the short time interval between the two earthquakes, of only 2 months, might have led to same reported damages also for the second event, and might not have been produced by it.

3.3. THE MAY 24, 2002 EARTHQUAKE

The earthquake from 24$^{th}$ of May 2002 occurred at 23:41 (local time), at a depth of approximately 10 km, with it’s epicenter situated at 12 km NE from Moldova Noua locality. Magnitude estimations done by various seismological agencies ranged from $M_w=4.5$ to $M_w=4.9$. In Figures 1 and 3b the location of the
epicenter is presented, around Moldova Noua locality, where maximum effects were observed (I=VII MSK). Another locality with the same effects was Sichevita, situated at 20 km from the epicenter.

For this earthquake, NEIC reported 5 persons slightly injured and damaging of some buildings in the SW area of Romania.

The macroseismic database for this earthquake is reduced, the received replies refer to positive information coming from 15 locations and 21 negative macroseismic questionnaires.

The effects observed in these localities and based on which intensities of VI degrees or higher were estimated, according to MSK scale, refer mainly to buildings, particularly to fissures, small cracks and fall of small pieces of the plaster from houses of type A (buildings with no anti-seismic protection: rural structures, adobe houses, clay houses) and a few of type B (ordinary brick houses). For instance, in Moldova Noua locality, the following damages on buildings were observed: open cracks in the inner and outer walls of brick buildings, damages of the church’s tower, as cracks. From people’s descriptions, specified in the MQs, it is shown that this earthquake was accompanied by a “loud noise, coming from the West”.

Fig. 3 – Isoseismal maps of a) the July 20, 2001 Vrancea subcrustal earthquake and of b) the May 24, 2002 Banat crustal earthquake.
Due to the influence of the local conditions, this earthquake has shown some anomalies of the seismic intensity, similar to those of the earthquake from July 12, 1991, with observed significant macroseismic effects at long distances, comparing to other localities situated close to the epicenter (for instance Deva city, situated at 145 km from the epicenter, with the same intensity of V MSK as for Naidas locality, situated at 13 km from the epicenter – Figure 3b).

3.4. THE NOVEMBER 30, 2002 EARTHQUAKE

Another Vrancea earthquake occurred at 11:16, local time, on 30th of November 2002, with a magnitude of $M_w = 4.7$ and an epicentral intensity of $I_0 = V–VI$ MSK.

Immediately after its occurrence, MQs were sent to the city halls of localities where the earthquake was felt, in order to be distributed to the population for filling in. From the total number of received MQs, 60 were positive and 44 were negative (the earthquake was not felt).

According to the provided information, this earthquake was felt on a large area, by most of people (situated indoors), the farthest point where it was felt being at 170 km NE from the epicenter (Miclesti, Vaslui). Still, NEIC informed that this earthquake was felt up to Chisinau city, in Rep. of Moldova (240km) ($I = III$ MM), and also felt in Bucharest. The map with the observed macroseismic intensities of this earthquake is shown in Figure 4a.

3.5. THE SEPTEMBER 27, 2004 EARTHQUAKE

The earthquake with a magnitude of $M_w = 4.6$ was generated on 27th of September 2004, at 09:16 UTC (12:16 local time) in the Western part of the Vrancea area, at a depth of 166 km.

This earthquake was followed by the moderate one on 27th of October, with the difference that the one from September, was generated in the deeper part of the Vrancea seismic volume ($h > 140$ km) [11], their epicenters being located at a distance of 18 km one from another.

The same seismological center NEIC reported that this earthquake was felt even in Bucharest (with no estimation of intensity), and also in Cahul and Chisinau, in Rep. of Moldova ($I = IV$ MM). The number of MQs for this earthquake was high, with 77 positive forms (and only 40 negative).

The maximum intensity for this earthquake was VI MSK, and was estimated for few localities situated at different distances from the epicenter (see Figure 4b). Intensity of V MSK was assigned for quite a large area, reaching North-East up to Tanacu, Vaslui county, South-East down to Pecineaga, Constanta county, and South down to Gradistea, Ilfov county. For this intensity, the observed and described effects in the MQs were referred, mainly, to the fact that this earthquake
was felt by everybody situated indoor, from which some people got scared and left the buildings, some unfixed objects moved and/or overturned, animals had a strange behavior, and also some other descriptions were given, particularly for this intensity degree. In few cases, small cracks in walls of the adobe houses, built before 1940, were reported.

Fig. 4 – The observed macroseismic intensities distribution of the November 30, 2002 and September 27, 2004 Vrancea subcrustal earthquakes.

3.6. THE OCTOBER 3, 2004 EARTHQUAKE

On 3rd of October 2004, a relatively moderate earthquake had occurred in the Northern part of the Dobrudja seismogenic zone, in the vicinity of Tulcea locality, at 06:02 local time, at a depth of 7.6 km, with a magnitude of mb = 5.0 (obtained from 130 stations), with the epicenter located at 11 km East from Tulcea locality. The parameters of this earthquake were taken from the earthquakes catalogue of the International Seismological Centre (ISC).

According to the information published on the ISC web-site, this earthquake was felt in Chisinau with an intensity of IV–V (reported by the Geophysical Survey of Russian Academy of Sciences – MOS) or V (reported by NEIC).

The macroseismic effects of this crustal earthquake were observed on a relatively large area, on the Romanian territory. The data obtained from the MQs show that this earthquake was felt in the Northern part of the country up to Iasi locality, Iasi county, in the South down to Independenta locality, Constanta county, in the South-West down to Cascioarele locality, Calarasi county and in the West up to Cosereni locality, Ialomita county.
From all six earthquakes studied in this paper, the event from 3rd of October 2004 generated in Tulcea area, has received the highest feedback concerning the positive responses, due to the large area where it was felt. From the total of MQs, 105 forms were useful to this study, the information was received from 84 localities.

From the MQs received from various localities (generally situated in Tulcea county) where the earthquake was “strongly” felt, there were reports of damages of some buildings (hairline and small cracks in walls), thus, the information regarding the year when the building was constructed and also the building vulnerability class were carefully analyzed, many of these buildings being constructed before 1940 or between 1940–1977, made of poorly quality materials (buildings of type A-adobe houses) and located in the vicinity or on crowded streets, thus trying to assess “an opinion” regarding the building state before the earthquake and assigning these damages only to the earthquake is quite a hazardous attempt. In such cases, the seismologist needs to take into account all the factors that lead to these damages and their origin, the macroseismic observations being correlated to other observed effects, thus the investigator should select, as much as possible, only the macroseismic effects.

In Tulcea county, the maximum observed intensity was VI MSK, being assigned to two localities (Tulcea and Valea Nucarilor), situated at the same distance (11 km) on one side and the other of the epicenter (Figure 5).

Fig. 5 – Isoseismal map of the October 3, 2004 crustal earthquake.
4. CONCLUSIONS

One of the conclusions of these macroseismic researches accomplished for six earthquakes refer to the state induced to people by earthquakes, considering the traumatizing experiences that people had in the past, during the destructive earthquakes from Vrancea zone. It is rightful to believe that people are so scared of earthquakes in such a way that changes the perception of the earthquake’s effects, being increased by fear, panic and high stress, sensations appeared from the beginning of the seismic shaking. Thus, the interpretation of the macroseismic information from the MQs becomes a very hard work and with high responsibility, in such a way that the results obtained from these researches have a very important role in attenuation studies and seismic hazard assessment on the Romanian territory.

Taking into account the large amount of earthquakes in Banat area, occurred since 1766 up to present, the maximum observed macroseismic intensities of VIII MSK, and the existence of numerous active faults situated at low depths with a high seismic potential [6], it is considered that the Banat zone is the second one as importance after Vrancea zone, from the seismic hazard point of view. Therefore, the macroseismic intensities distribution of the shallow earthquakes from Banat and Dobrudja zones is of great importance for the seismic hazard studies in these zones, these being characterized by a moderate to high seismic potential, and this is the reason why these areas are particularly of interest, both from theoretical and practical points of view. Moreover, the obtained macroseismic intensities will be included in the macroseismic database and will be used in attenuation studies, particularly those of crustal earthquakes.

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