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THE INTENSITY ASSESSMENT OF THE APRIL 25, 2009, VRANCEA SUBCRUSTAL EARTHQUAKE FROM MACROSEISMIC DATA

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Abstract. On April 25, 2009, at 20:18:48 (local hour) the Romanian territory was shaken by a moderate size earthquake centred beneath the bending area of the south-eastern Carpathians, in the Vrancea seismogenic region (Romania). In the present paper we present intensity map, macroseismic intensities, and community observations of effects for the M_W = 5.4 Vrancea subcrustal earthquake of 25 April, 2009. For many locations, for the estimation of the macroseismic intensities besides questionnaires other type of sources such as press reports, internet were used. The highest intensity assigned for this Vrancea earthquake was VI MSK, estimated for eleven locations, situated in the north-eastern part of Vrancea seismogenic zone, which include parts from Vrancea, Bacau, and Galati counties. At the lowest intensities, the 2009 earthquake was felt to a distance of 500 km from the epicenter, in Rep. of Moldova, Bulgaria, Ukraine, and Serbia. A non-uniform distribution of intensity resulted for locations on different directions from the epicenter. A scatter of as much as one-two intensity units were observed for places situated very close. The comparison of the intensity areas for the October 27, 2004 and April 25, 2009 moderate subcrustal earthquakes of the Vrancea seismogenic zone was performed.

Key words: Vrancea seismogenic zone, subcrustal earthquake, macroseismic questionnaires, intensity map.

1. INTRODUCTION

Nowadays, a great interest is given to studies regarding the evaluation and re-evaluation of the macroseismic information from the earthquakes generated in historical, when there was no equipment to record the strong ground motions, and instrumental periods. These researches imply the interpretation, re-interpretation and re-quantification of the macroseismic effects produced mainly by significant and major subcrustal earthquakes occurred in Romania. Mostly, the research regarding the re-evaluation of the macroseismic information is necessary in order to eliminate some suspicions about a potential underestimation of the previous macroseismic maps, as well as due to the finding of some new sources that include

some observations about earthquakes effects produced during both periods of time [1].

The macroseismic intensity, being an unlimited time parameter (covering both instrumental and non-instrumental periods) is the only one (the best) to indicate the severity of the damages produced by earthquakes. Therefore, nowadays, with all the ampleness of the seismological instrumental networks (accelerometers, velocimeters, displacemeters) [2], the macroseismic maps still have an important role in the antiseismic design of constructions (seismic engineering), in seismological and engineering research, and furthermore, the evaluation of the seismic intensity parameter is very useful for the governmental and intervention institutions in case of emergency situations and for the national insurance programs against the natural disasters. Moreover, the recent development of automatic procedures for the collection and analysis of macroseismic data represent a huge advantage for reduction of uncertainties caused usually by the inherent subjectivity which occurs in the interpretation of the macroseismic information and estimation of the intensity values. The properties and distribution of the macroseismic intensity can be used for estimating: i) earthquakes epicenters, (ii) focal depths, (iii) near-field and far field absorption, coefficients, (iv) event's magnitude, (v) future strong ground motions or, generally, (vi) the long term seismicity of a territory and, of course, (vii) the intensity is used for the seismic hazard assessment, and seismic scenarios (including worst case) [3, 4]. Likewise, the macroseismic data are very useful in selecting and developing of some predictive ground motion equations, which are determined either based on the intensity values compared with values from other areas with similar geological and tectonic characteristics [5, 6] or by direct correlation/comparison of the intensities with the PGA values [7, 8]. Seismic-intensity data derived on the basis of questionnaires can be also used for advanced studies of seismic-source properties, propagation-path characteristics and site effects, as well as for comparative studies involving other seismological data [9, 10].

The main purpose of this paper is to evaluate the macroseismic effects of the intermediate depth earthquake generated on the evening of 25th of April 2009, at 20:18:48 (17:18:48 UTC) in Vrancea Seismogenic Zone (Table 1). This moderate earthquake is one of the recent important earthquakes occurred in Romania (for example: 6.10.2013, M_L = 5.5; 24.09.2016, M_L = 5.3), with the epicenter located in the South-Eastern Carpathians, known as the Vrancea Seismogenic Zone (VSZ). However, the strongest earthquake (considering recent events, after 2000) was the earthquake from 27th of October 2004, occurred in the same area and considered the only significant seismic event of the last two decades, both in terms of magnitude (M_w = 6) and observed macroseismic effects (I_{max} = VII MSK).

Table 1

Parametric estimations for the main shock from key reporting agencies

Agency	Location		Focal depth (km)	Magnitude				
	Latitude N	Longitude E		M_D	M_L	mb	M_s	M_w
NIEP	45.68	26.62	109.6	5.7	6			5.4
EMSC	45.70	26.63	96			5.3	4.2	5.2
USGS	45.67	26.52	100.7			5.3		5.2
ISC	45.70	26.53	102.4			5.3		

NIEP National Institute for Earth Physics; *EMSC* European-Mediterranean Seismological Centre, *USGS* United States Geological Survey; *ISC* International Seismological Centre.

The first information received just after the earthquake emphasize that the seismic event from April 2009 was felt in the extra-Carpathian area, and also in the trans-border areas (Republic of Moldavia, Bulgaria, Ukraine and Serbia) (information confirmed by the international agencies).

According to USGS, the earthquake from April 2009 was felt with an intensity of V MM degrees in the epicentral area and of III–IV MM degrees in Bucharest. Moreover, the earthquake was felt on a large area, extended at NE up to Iasi and Chisinau, and at SW down to Pitesti, Craiova and even Bulgaria. ISC gave the following information for this earthquake: the earthquake was felt with an intensity of III MM at Bucharest, Tulcea and Voluntari (Ilfov); I = II MM at Craiova, Slatina and Vaslui. Additionally, it was mentioned that the earthquake was felt also in Adjud, Alexandria, Bucov, Caracal, Chiajna, Corbeanca, Gheorgheni, Giurgiu, Miercurea-Ciuc and Suceava. For Shumen, Svishtov and Tutrakan localities, the estimated preliminary intensity was IV MM. In Belene, Isperikh, Levski, Lom, Pleven, Silistra, Varna, Veliko Turnovo and Vidin localities, the earthquake was felt with an intensity of III degrees on MMI. An intensity of II (MM) was estimated in the cities of Burgas, Sofia and Ruse (Bulgaria). Furthermore, the event was felt in Dve Mogili, Gabrovo, Kozloduy, Razgrad, Sliven and Stara Zagora. It was also felt in Basarabeasca and Kishinev (Republic of Moldova), in Bor (Serbia) and Ismayil (Ukraine).

In order to achieve this study, all the collected information were analyzed immediately after the earthquake occurrence, the most important and numerous being the macroseismic questionnaires filled with the macroseismic effects observed in the areas were the seismic motion was felt. In order to elaborate the macroseismic map, the collected data were processed and interpreted, and the data base was achieved with the macroseismic intensity values obtained after the evaluation of the information from macroseismic questionnaires and correlating the effects with geophysical and geological data. The final result of the study is represented by the macroseismic map of the Vrancea earthquake from 25th of April 2009.

2. METHODOLOGY OF THE MACROSEISMIC INVESTIGATION

Macroseismology is the part of seismology that collects, stores, sorts and evaluates the non-instrumental data on earthquakes, for example: the macroseismic effects of humans, objects, buildings and nature (geological and environmental) [11]. The data are, usually, collected through macroseismic questionnaires, sent to the area were the earthquake was felt. In the case of strong earthquakes, the field investigations are mandatory activities, which complete those of collecting the macroseismic questionnaires. The rapid development of technology has significantly reduced the necessary time for collecting the information after earthquake, but many of the descriptions of the effects have not changed too much. People are still awaken by the noise of glass objects and windows, they panic and leave their houses when different objects start to fall from shelves and are, in general, frightened by the Earth's shakes, more or less in the same way as during the XVth Century or any other Century [11]. The macroseismic survey using questionnaires performed in the felt areas and the estimation of intensities follows the macroseismic methodology described in the European Macroseismic Scale (EMS-98) support material [12] and in the New Manual of Seismological Observatory Practice – versions 1 and 2 [13, 14].

In brief, in order to accomplish a complete macroseismic investigation, few important steps have to be followed, such as: elaboration of the macroseismic questionnaire (MQ) used for collecting the macroseismic information, selecting the modality to distribution and collection of the MQs (*i.e.*: mail, e-mail, fax, web, etc), processing and interpretation of the observations from MQs, estimation of the macroseismic intensities and, of course, construction of the macroseismic map.

3. MACROSEISMIC DATA COLLECTION

In Romania, the collection and analysis of the macroseismic data is accomplished by the NIEP, the only institution “approved” to conduct such studies, and having as purpose to evaluate the effects produced by Romanian earthquakes. This represents an important activity among the researches of the institute, and especially of the Research, Development, Innovation in Earth Sciences Department (RDIESD).

Immediately after the earthquake occurrence, the former Seismological Research Department (part of the RDIESD) of NIEP sent macroseismic questionnaires in all affected areas in order to be filled in, with the purpose of macroseismic intensity estimation in each location. The questionnaires were sent to the local authorities from each locality/county to be distributed to the population for filling in and then sent back to NIEP.

The filled questionnaires were further sent to NIEP by the majority of the authorities, through email, fax and of course conventional way such as mail. Other

macroseismic information used in this study were compiled from different sources such as internet (for example: newspapers forums) and *European-Mediterranean Seismological Centre* (EMSC) (Fig. 1). However, in some of the cases, the observations written on some websites do not contain detailed descriptions of the effects observed by those who posted the information regarding the earthquake in question. On the other hand, only few intensity data points (IDP) were obtained based on the information provided by the EMSC website, where this was the only information source (see the IDP for Bulgaria and Rep. of Moldova).

The total number of locations from where the information was collected is 778, and their spatial distribution is presented in Fig. 1. Moreover, there were some MQs which could not be used due to the fact that the recorded answers/observed effects were reduced or ambiguous, and could not be, thus, used in the process of the intensity evaluation.

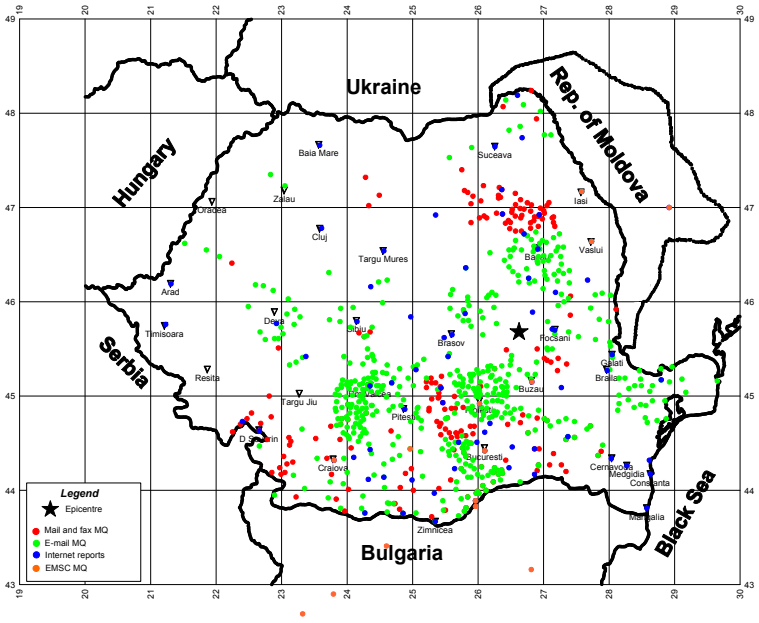

Fig. 1 – Spatial distribution of macroseismic observations collected and analyzed for the 25 April 2009 Vrancea subcrustal earthquake. The black star indicates the earthquake epicenter.

The analysis of all the collected observations from the field, suggests that from the total number of information, 1184 were considered positive, containing useful information for the macroseismic intensity assessment. As mentioned before, a very high number of MQs were received by email, from most of the areas where the earthquake was felt, fact that proves the efficiency and the fast development of the method, being adopted by a higher number of people (Fig. 2).

For the localities where the number of received/collected MQs was larger, a higher degree of coverage is suggested, thus increasing the confidence level in the evaluation of the effects and assessing the macroseismic intensity for those locations. A high number of MQs was received from the areas where the earthquake was not felt (304 MQs). Those localities had an NF qualification and their number is presented in the plot from chapter 6.

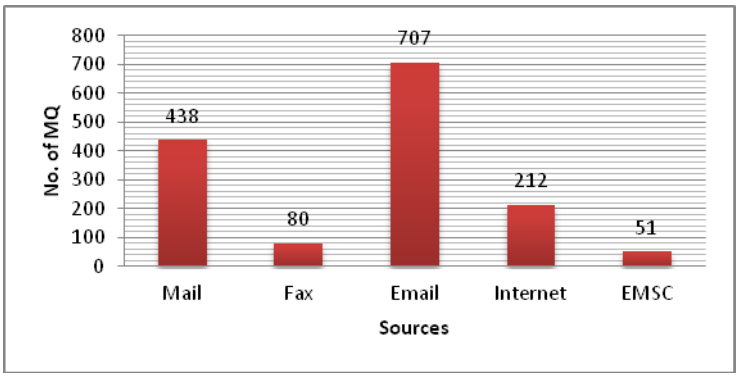

Fig. 2 – Number of macroseismic observations collected through various sources and used to create each IDP.

After analyzing the IDP database, one can state that some intensities were estimated based on one or two MQs/observation. However, the database contains IDP's based on at least 5 observations. The most trusting IDP's are those with at least 10 MQs/observations (Fig. 3).

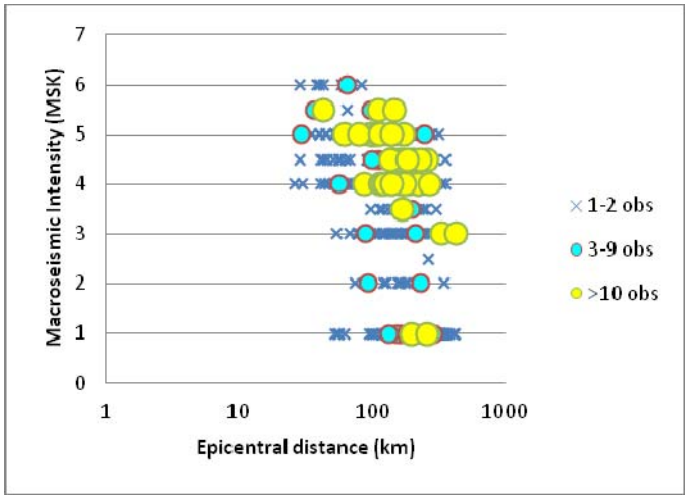

Fig. 3 – Distribution of IDPs plotted as a function of Log (epicentral distance), with symbols indicating the numbers of observations used to estimate intensity for each site.

4. MACROSEISMIC INTENSITY ASSESSMENT

The macroseismic intensity assessment and implicitly the elaboration of the macroseismic maps implies a complex analysis and interpretation of the existing information through the questionnaires filled in and returned from the field, regarding the macroseismic effects observed, immediately after the earthquake occurrence. Still, as in any such activity, a series of deficiencies might appear, caused by different factors: people's refusal to fill in the questionnaires (*i.e.* the NE part of the country), the defective mail service; description of the observed macroseismic effects; the preparedness and responsibility degree of the respondents from the territory, observed in the answers to the questionnaires [15]. For the macroseismic investigation of the 24th of April 2009 earthquake, event studied in this paper, a series of these factors have negatively affected the raw information, mentioning: the low number of questionnaires returned from some counties such as Vaslui, Iasi, Suceava, Braila; the ambiguity of some answers from the questionnaires, confusions, etc.

After collecting the macroseismic information, the following steps in the process of obtaining the intensity values imply: sorting and arranging the data for each county, respectively for each locality, and conversion of these information in numerical values, based on the macroseismic intensity scale (the observed effects for each location, were first combined and then the intensity value which best fitted most of the data was determined). The assessment of the intensity is based on the damages observed to the building stock and on the human perception of the effects caused by the earthquake. In other words the evaluation is done by identifying which of the descriptions for the various intensity degrees best fits all data collected for each analyzed location (*e.g.* [16]). This means that the correct estimation is the one that best expresses the generality of the macroseismic observations [17, 11]. Nevertheless, considering that the observed effects were not strong enough to produce damages (significant constructions failures), for most of the localities the assessment was mainly based on the human perception (human behavior and effects on objects).

The evaluation of the collected macroseismic information was accomplished according to the prescriptions of the Standard „Seismic intensity scale – MSK" [18, 19], being displayed as intensity values, thus obtaining the macroseismic database of the 25th of April 2009 earthquake. This was done in order to keep the continuous macroseismic studies carried out for previous earthquakes and in order to ensure the homogeneity with the existing macroseismic database (meaning, the collected intensity data up to present days from Romania are in accordance with the MSK

scale), and, last but not the least, as mentioned above, due to the fact that this scale is still in effect in Romania.

5. DESCRIPTION OF THE MACROSEISMIC EFFECTS PRODUCED BY THE EARTHQUAKE

The macroseismic effects of the Vrancea earthquake from 25th of April were observed on an extended area of Romania. It results from the MQs that this earthquake was felt in the northern part of the country up to Darabani, Botosani county, to the S down to Turnu Magurele (Teleorman), in the SV to Eselnita, Mehedinti county (350 km to epicenter), in SE down to Mangalia (Constanta) and in the W up to Cluj-Napoca (Cluj). The maximum effects of this earthquake appeared in the localities from the epicentral area but were not strong enough to cause material damages and human injuries. The epicentral intensity reported by the National Seismic Network Department (of NIEP) was V–VI, and the observed maximum intensity was estimated to VI, according the MSK scale.

The macroseismic information collected after the earthquake resulted in no reported significant damage to buildings, except the appearance of small to open cracks in the walls and cracks of the chimneys, and the fall of fragments of plaster in the houses located, mainly, in the localities from the epicentral area (the area that covers a great part of Vrancea, Bacau and Galati counties). These damages appeared in the walls of buildings from class A (buildings with no anti-seismic design built from field-stone, clay and adobe dwellings) and also at some buildings from class B (ordinary brick buildings, and hewn stone buildings), according to the types of structures from the MSK intensity scale [18]. Other observed effects for the VI intensity degree and described in the MQs were the following: ".... many people were scared and left their houses, some people on the move lost their balance, in some buildings a light furniture pieces overturn was observed, few glass articles and dishes were broken, some unfixed objects (books and others) overturned and/or fell from the shelves".

For the case of intensities V and V–VI MSK, those were attributed to the localities with a higher number of descriptions referring to the panic produced by the earthquake, the seismic oscillations being described as strong: "*shaking the hole building*", most of the people got frightened and some even left their homes. In some cases, displacements and/or falling of some unfixed objects, like vases and other glass articles, displacement of paintings on the walls were observed and also other descriptions were made, which are in accordance with this degree of intensity. In few cases some cracks (small cracks) in the walls of some buildings

from class A were reported. Another description from many MQs refers to the agitation state of animals (birds, dogs) before and after the earthquake. Among the strong seismic oscillations, the panic triggered by the fear was amplified by the noise (sound effects) produced during the earthquake.

Below we provide a brief description of the macroseismic observations for some locations within the epicentral area. For instance, in Tamboiesti (Vrancea county), locality situated at 38 km from the epicenter, the following effects were noticed: small cracks in walls, falling of fragments of plaster (damage of grade 2) from the walls of houses of type A, and in a few of type B; many people from inside got scared and ran outside; falling of objects were reported, such as dishes and other glass articles, and some of them were even broken. Based on these effects for Tamboiesti locality, an intensity of VI MSK was assigned. Similar effects were observed in Onesti (Bacau county), located 64 km from the epicenter, in Campineanca (Vrancea county) located at 39 km E from the epicenter, and also in Colacu (Vrancea county), located at 28 km, such as:" the majority of people both from inside and outside felt the earthquake, many people got scared and ran out in the street, there were cases of people losing their balance, few vases and other glass objects broke, some unfixed objects (books and others) overturned and/or fell from shelves, and, of course, minor to moderate damages to houses".

6. THE MACROSEISMIC MAP OF THE 25th OF APRIL EARTHQUAKE

As mentioned above, for this earthquake a maximum intensity of VI MSK degrees was estimated, attributed to a number of 11 localities (Fig. 4). All these localities are situated at distances from 28 to 83 km from the epicenter. For those, the evaluation of the intensity was mostly based on effects observed on buildings. Thus, the intensities of VI MSK degrees were attributed to locations where damages to buildings were reported. The distribution of the macroseismic intensities evaluated for this earthquake is represented in Fig. 4. When analyzing the macroseismic map, one can notice that for the sites located near the epicenter, there is an alternation of VI and V intensities, and also locations with intensities of V–VI MSK (values between those two degrees). The instrumental epicenter is located in the Western part of the area where the highest intensities were recorded. With no information for the localities of the counties from the NNE part of the country it's hard to estimate the real image of the macroseismic field of the Vrancea earthquake from 2009, respectively on the distribution of its effects. The numerical distribution of the intensity degrees is presented in Fig. 5, from which we can notice that for many of the IDPs, more precisely 241, an intensity of V MSK was estimated.

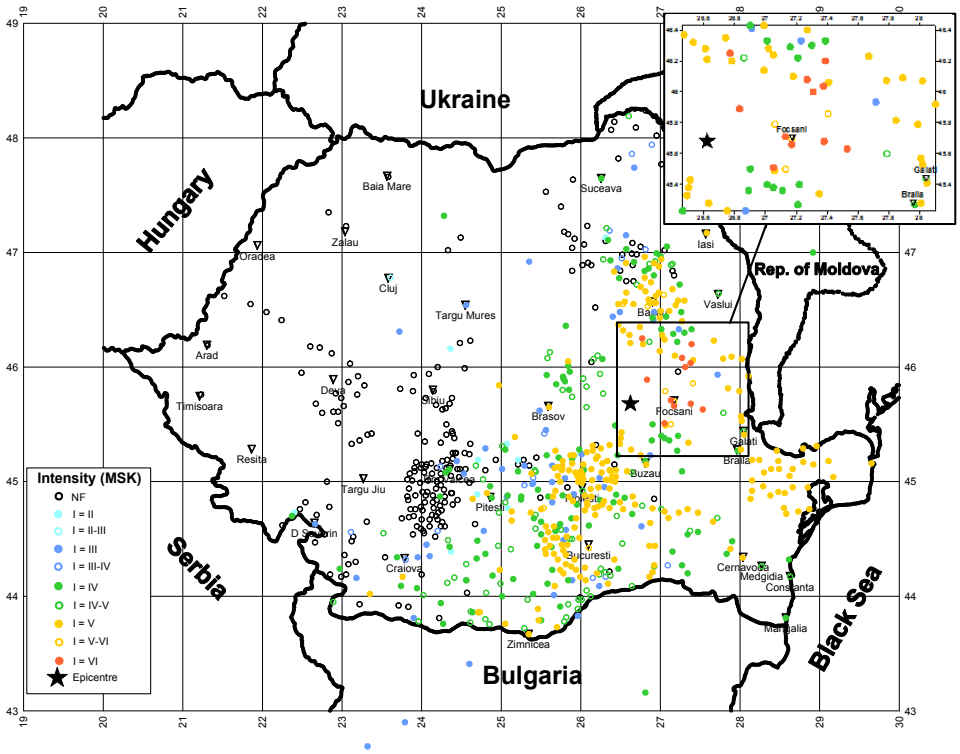

Fig. 4 – Macroseismic map of the April 25, 2009 Vrancea subcrustal earthquake. An enlarged view of the rectangular area corresponding to the intensity distribution in the proximity of the epicenter.

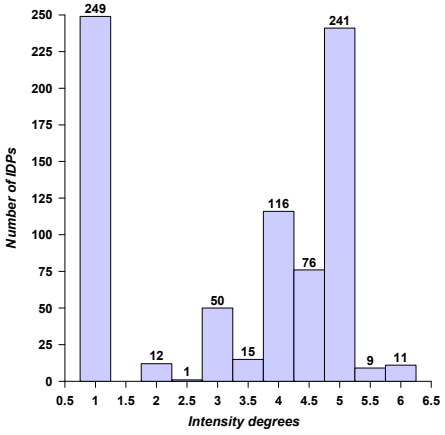

Fig. 5 – Number of IDPs obtained for each MSK intensity level. In this plot I = 1 means that the earthquake was not felt in those localities (I = NF).

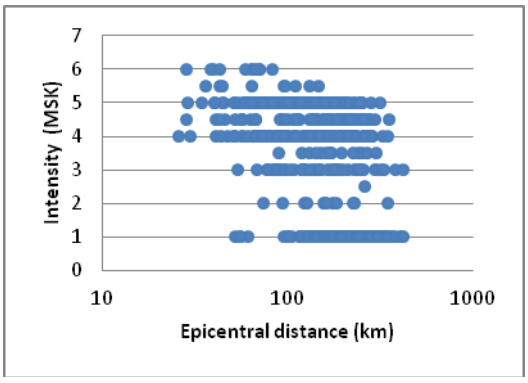

Fig. 6 – The intensity–distance plot for the IDPs obtained for the 25 April 2009 Vrancea subcrustal earthquake.

Figure 6 displays the intensity-epicentral distance plot, having the purpose to better understand the distribution of the obtained IDPs. Therefore, this plot emphasizes the importance of the collected data and reflects the level of intensity attenuation with distance, respectively the seismic waves attenuation in the area. However, as one can observe from the plot, the intensity distribution in areas where the earthquake was felt do not indicate an attenuation/gradual decrease of the intensity with distance (meaning that it indicates a low attenuation of the intensity with distance). For example, intensities of V MSK degrees were observed also at distances of 200–300 km from the epicenter. These anomalies could be caused by the local effects due to geological conditions. The estimated intensity values for locations situated approximately 250–300 km from the epicenter, or even farer, are higher than expected considering their epicentral distances.

7. THE COMPARISON OF MACROSEISMIC EFFECTS IN CASE OF 2009 AND 2004 VRANCEA SUBCRUSTAL EARTHQUAKES

According to Romplus catalogue the hypocenter and magnitude of the Vrancea 2004 earthquake are as follows [20]: Origin time: 27 October 2004, 20:34:36.0 UTC; Epicenter: 45.84N and 26.63E, Depth: 105.4 km, Magnitude: M_W 6.0. The Vrancea earthquake of October 27, 2004 had hypocenter that was similar to this of the April 2009 earthquake occurred in the same region. The instrumental epicenter for the 2004 earthquake is about 16.5 km North of that of the 2009 earthquake. The hypocenters are in the same volume with a difference between them of 4 km.

We have compared macroseismic effects on the territory of Romania of the April 25, 2009, with that from October 27, 2004. For this comparison we used the intensity values of 2004 earthquake obtained by Constantin and Pantea (2013) [21] (Figs. 7 and 8). Macroseismic intensities for the 2004 and 2009 earthquakes were assigned using the same scale (MSK-64) in this way being no problem to compare intensities for the two earthquakes. The maximum effects on the territory of Romania after the 2009 earthquake reached intensity VI. In 2004 the maximum observed intensity on the Romanian territory was VII (Fig. 7). The intensity VII for the earthquake of 2004 covers the entire bending area of the Carpathians (the area that covers a great part of the Vrancea, Buzau, and Prahova Counties), and in 2009 only in the northern part of this area tremors achieved intensity VI.

During the 2004 earthquake the intensities of IV are extended towards N and SSW of the extra-Carpathian area, as in the case of the 2009 earthquake, but for this last earthquake the areas were not so extended. On the Romanian territory the tremors with intensity IV reached locations situated in the N and W boundaries of the country for both earthquakes. The 2009 earthquake with the epicentre in North-

Eastern part of Vrancea area had maximum effects to the Northeast of epicenter. In the case of the 2004 earthquake maximum effects were observed in the Southern part of the epicenter. On the basis of macroseismic effects, we infer that shaking in the epicentral area was less for the 2009 earthquake than for the Vrancea earthquake of October 27, 2004, which had nearly the same hypocenter. However, the earthquakes from 2004 and 2009 differ in magnitude (M_w = 6 and M_w = 5.4). Obviously, the overall field of intensities of the 2004 seismic event was with one degree higher that of the 2009 earthquake.

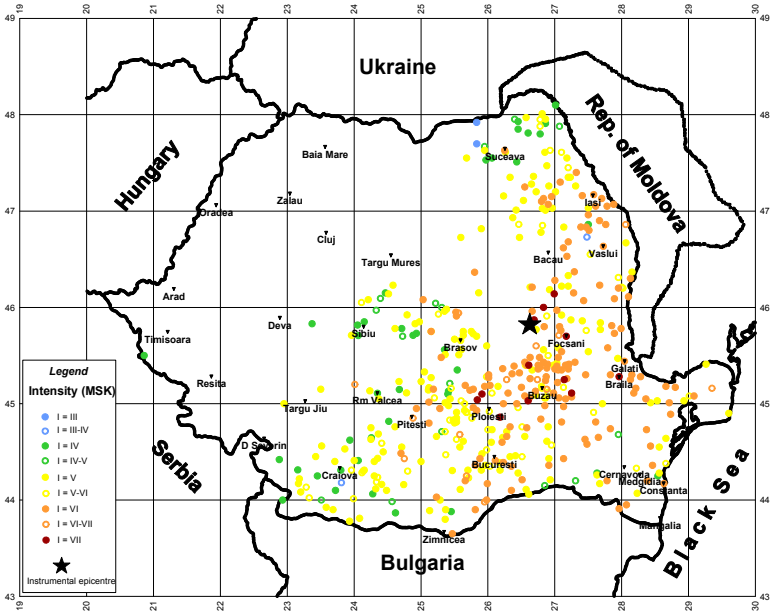

Fig. 7 – Intensity map of the October 27, 2004 earthquake [21].

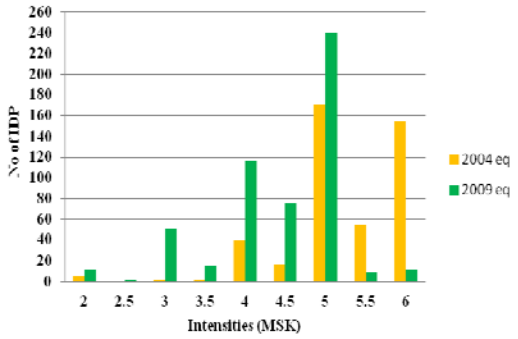

Fig. 8 – The comparison of the intensity values for the 2004 and 2009 moderate earthquakes of the Vrancea zone.

8. CONCLUSIONS

The macroseismic effects of the Vrancea earthquake from 25th of April 2009 were evaluated based on the data collected through the MQs and not only. The macroseismic investigation of the produced effects was accomplished for 530 localities (IDPs with values between II and VI MSK degrees), most of them being located in the extra-Carpathian area. The maximum observed intensity was estimated as VI, according to the MSK scale, and was attributed to some cities located at different distances from the earthquake epicenter. The macroseismic intensity distribution suggests a weak attenuation, emphasized by the existence of intensity values higher than it was expected for their epicentral distances. This might be explained by the existence of local negative conditions of the soil in such locations. Also the intensity map shows that the area with highest intensities is concentrated toward the North-Eastern part of the epicenter having intensity VI which may be due to earthquake directivity or site effects. As a final conclusion, we must underline that this earthquake lead to obtaining new valuable information regarding the Vrancea earthquakes effects. These intensity values were included in the macroseismic database of the Romanian earthquakes, and will definitely be used for the seismic hazard assessment in the cities affected by these earthquakes and in the areas with strategic objectives from Romania [22].

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