CORRELATIONS BETWEEN MACROSEISMIC INTENSITY VALUES AND GROUND MOTION MEASURES OF VRANCEA (ROMANIA) SUBCRUSTAL EARTHQUAKES

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Abstract. The correlations between *macroseismic intensity* (MI) and strong ground motion parameters such as *Peak Ground Acceleration* (PGA) and *Peak Ground Velocity* (PGV) for the Vrancea subcrustal earthquakes are compared. The recent Romanian earthquakes, especially Vrancea earthquakes provide valuable data to examine the correlation relationships between these parameters for the entire territory of Romania. The goal of this study is to develop a new empirical relationships between the strong ground-motion records and the observed intensities for major and moderate earthquakes with Mw ≥ 5.4 and epicentral intensity in the range VI to IX MSK degrees that occurred in the period 1977–2009. For each instrumental record we assigned a macroseismic intensity based on the proximity of the site where reported value are available (no more than 3 km distance around the station). The obtained relations between macroseismic intensity and PGA/PGV will be given both as a mathematical equations, but also as corresponding ground motion intervals. The most prominent results available in the literature have shown that macroseismic intensity and ground parameters do not always show a one-to-one correspondence, and the errors associated with the intensity estimation from PGA/PGV are sometimes +/–2 MSK degree. These relations can be used as near real-time response regarding ground shaking severity, and potential damages in the areas affected by the Vrancea earthquakes.

Key words: Vrancea seismogenic region, subcrustal earthquake, macroseismic intensity, peak ground acceleration, peak ground velocity.

1. INTRODUCTION

The past tragic experience caused by worldwide natural disasters, especially those associated with major earthquakes which has determined defensive measures from the international communities. In high seismic risk regions, prevention and protection measures of the population and infrastructure have to be applied, including the anti-seismic design of critical and essential facilities. Very important parameters used in such studies are *macroseismic intensity* (MI) and *ground motion parameters* (PGM), these parameters describing the degree of ground shaking for earthquakes [1–2]. Moreover, the use of the macroseismic intensity in earthquake engineering was necessary due to the fact that instrumental seismology only appeared at the end of the XIXth Century. On the other hand the macroseismic information date since the first centuries, and in Romania, the first sustained macroseismic investigation was accomplished in 1892 [3].

With the advent of seismic networks and the availability of past records, were developed relationships between macroseismic intensity and instrumental records in order to obtain the relevant values of macroseismic intensities in the locations where only the ground motion parameters were available or *vice versa*. In this way, the large amount of observations from pre-instrumental earthquakes in terms of macroseismic intensity can be converted into instrumental intensity using these correlation relations. The data characterizing the seismic ground motion is very important for the seismic hazard assessment, which emphasizes the particularities of the active or potentially active seismo-tectonic sources from the Romanian territory [4–6].

One of the first attempts to correlate macroseismic intensity and ground motion parameters was made by Medvedev, Sponheuer and Karnik [7] in their intensity scale (the scale that is still in use in Romania), who proposed a range of PGA and PGV for each degree of intensity [8].

In Romania, first attempts regarding the analytical relations MI-PGM for the Vrancea subcrustal earthquakes were made by various authors (*i.e.* [9–12]). The system of quantification of the seismic motion severity was used starting with the occurrence of the earthquakes from 1986 and 1990, when numerous valuable instrumental records were obtained [13].

The main goal of this study is to develop new relations that can be used to estimate very quick macroseismic intensities of the recent intermediate-depth earthquakes, which accelerations and velocities are known, as well as inferring approximated values of seismic intensities during future earthquakes.

2. DATA SET

In order to derive relevant correlations between macroseismic observations and instrumental measures were used the accelerations and velocities recorded in various points from Romania by the strong motion networks during strong and moderate earthquakes, and their associated macroseismic values resulting relations for MI-PGM for $I \geq V$. Bellow it's provide summary statistics about the earthquakes parameters, including date, location, magnitude, depth, epicentral intensity [14], the number of related recorded ground motion parameters, and IDPs (Table 1). Figure 1 shows the spatial distribution of the selected seismic events and the location of the stations.

Table 1

Parameters of the earthquakes used in this study

No.	Date	Time	LatN	LongE	h (km)	Mw	Io (MSK)	No of IDP	No of records
1	04.03.1977	19:21:54	45.77	26.76	94	7.4	IX	1620	2
2	30.08.1986	21:28:37	45.52	26.49	131	7.1	VIII-IX	950	75
3	30.05.1990	10:40:06	45.83	26.89	91	6.9	VIII	705	74
4	31.05.1990	00:17:48	45.85	26.91	87	6.4	VII	510	52
5	27.10.2004	20:34:36	45.84	26.63	105	6.0	VI	475	41
6	25.04.2009	05:18:48	45.68	26.62	109	5.4	VI	531	47

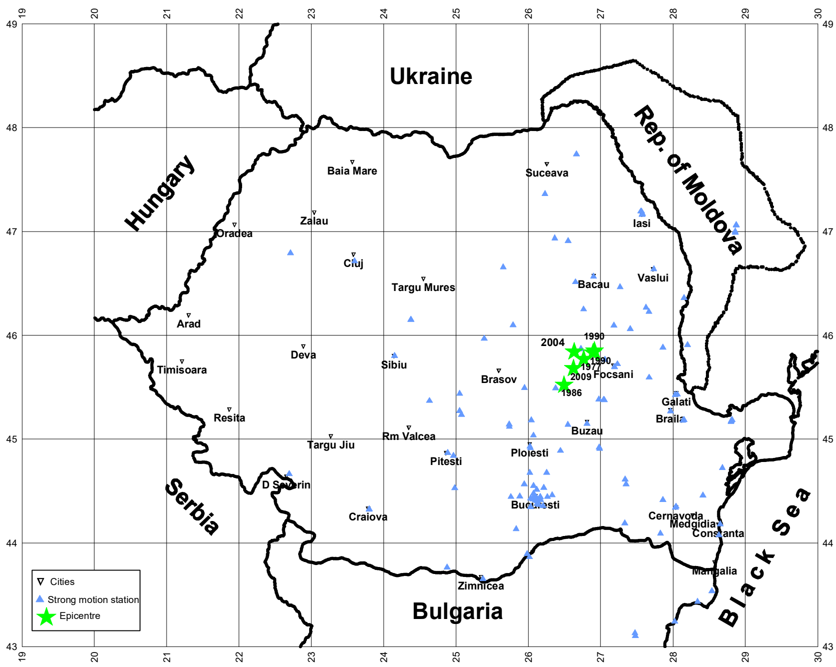

Fig. 1 – The epicenters of the studied seismic events (green stars) and the strong ground motion network that recorded these earthquakes (blue triangles).

Before March 4, 1977 earthquake the number of accelerometers was very low and accelerometer recordings of this earthquake were obtained only in Bucharest. After the 1977 earthquake the Romanian seismic network developed rapidly, thus, in 1980 the Romanian accelerographic network had already increased to 78 instruments. The number of strong-motion stations kept increasing until the ‘90, thus for the earthquakes from August 30, 1986, May 30, 1990, and May 31, 1990, around 160 recordings were obtained, in more than 40 points [15]. These strong-motion stations were switched in 1997 to a new network using K2-digital accelerographic, and nowadays the national seismic network consists of 147 stations, equipped with velocity and/or acceleration sensors, a *short period* (SP) and/or *broad-band* (BB).

Macroseismic intensity values have been extracted from three different sources: (1) from past macroseismic studies available in the literature [16–18], for seismic events occurred in 1986 and 1990; (2) from macroseismic database resulted after the reevaluation of the effects produced by the 1977 earthquake [19]; (3) from post-earthquake macroseismic questionnaires surveys performed by a small team from NIEP [20–21], for earthquakes occurred in 2004 and 2009.

To show which earthquakes are best reported in terms of both IDP and PGM, the number of both types of data for each earthquake is presented in Figure 2. The number of IDP varies, with a minimum of 475 for the M 6.0 October 2004 event to a maximum of 1620 for the M 7.4 March 1977 event. The maximum values of PGA and PGV assigned from the horizontal components of the ground motion records have been considered in the correlations with macroseismic intensities.

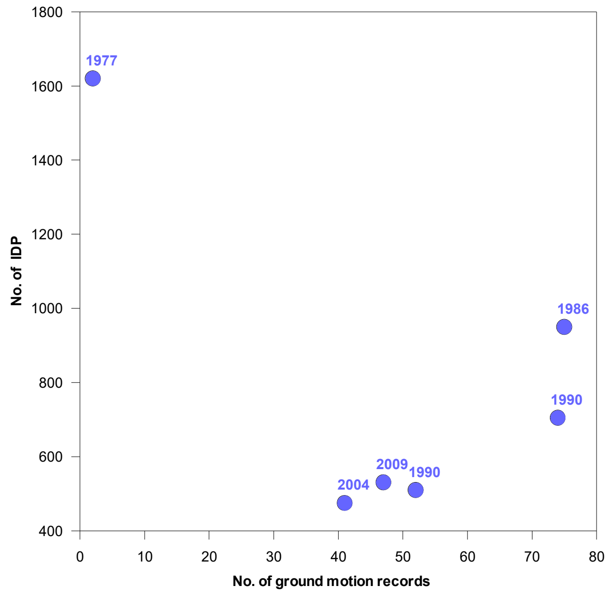

Fig. 2 – The number of IDP *versus* number of PGM for all 6 events.

In addition, maps with the ground motion parameters were constructed, corresponding to all the studied earthquakes. In Figure 3 are presented only macroseismic maps and PGV distribution maps for five earthquakes (1986÷2009 earthquakes).

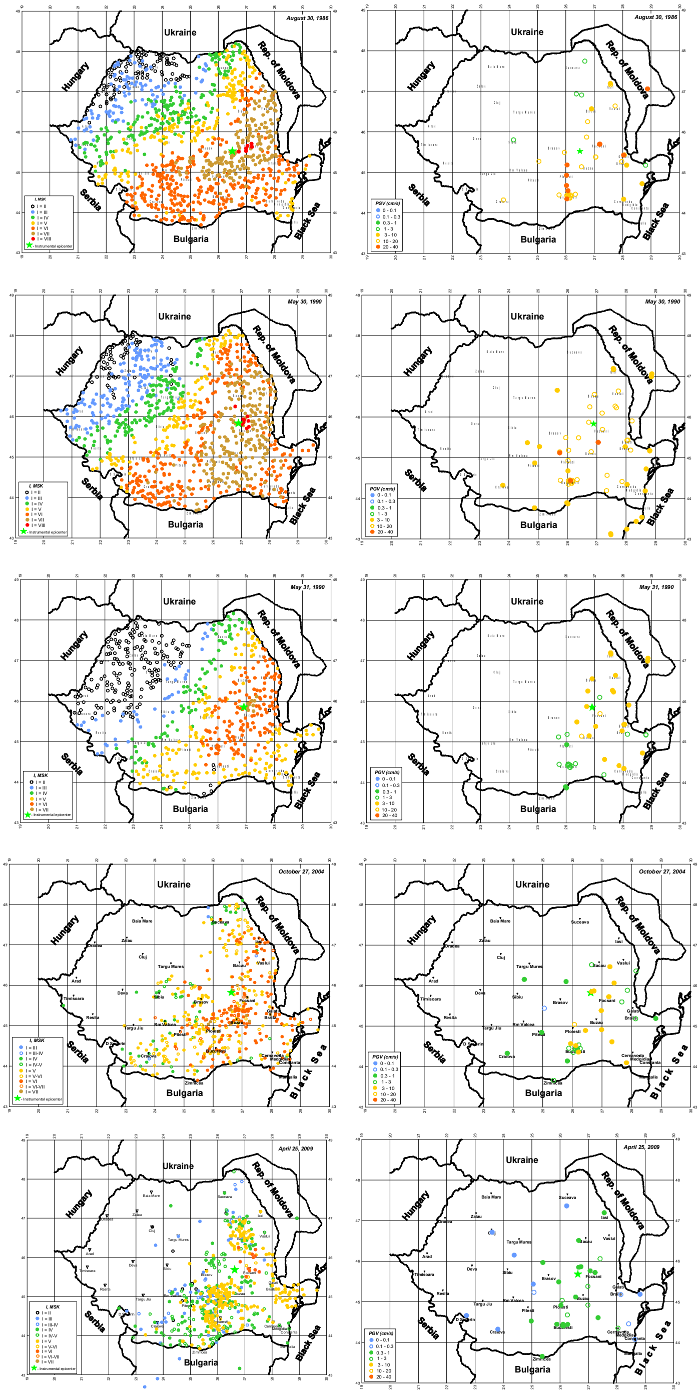

Fig. 3 – Macroseismic intensity and PGV maps for the studied earthquakes.

3. THE RELATION BETWEEN MI AND PGM FOR SUBCRUSTAL EARTHQUAKES

Using the above described seismic data, in this section statistical regressions by considering MSK macroseismic intensities and two instrumental parameters, *i.e.* peak ground acceleration and peak ground velocity have been deduced and analyzed. The final dataset consists of 218 pairs of MI-PGM from six intermediate-depth earthquakes. To show the correlation between these parameters, to calculate MI and to obtain the ranges of PGA and PGV we have used in this study only the linear least-squares regression. First, we performed a simple regression of intensities *versus* accelerations and velocities for all the stations and some of them showed a large scatter. Next, the geometric mean was calculated for PGA and PGV for each intensity level. Finally, the linear least-squares regression method was performed on the macroseismic intensities and the geometric mean of the PGM as the only independent variables.

$$MI = 3.724 \cdot \log PGA - 0.355,\ R^2 = 0.969,\ \sigma = 0.102 \quad (1)$$
$$\text{(for the interval of } V \leq MI \leq IX)$$

$$MI = 2.895 \cdot \log PGV + 4.299,\ R^2 = 0.945,\ \sigma = 0.184 \quad (2)$$
$$\text{(for the interval of } V \leq MI \leq IX)$$

The results of intensities correlation with PGA and PGV for the six Vrancea subcrustal earthquakes are plotted in Figure 4.

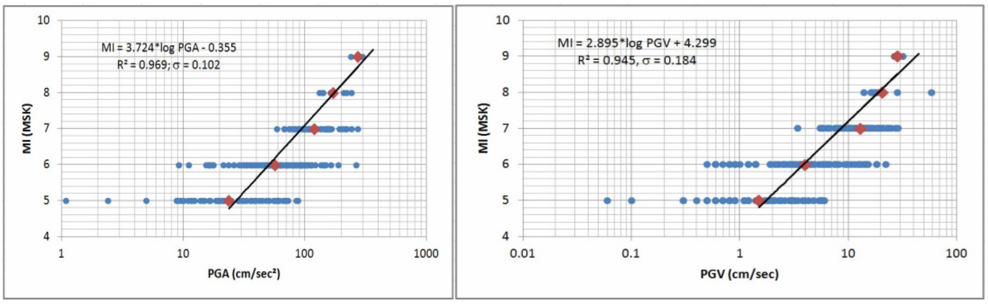

Fig. 4 – MI *vs* PGM correlation for the six Vrancea subcrustal earthquakes. Blue dots denote data and black solid line the regression for the geometric mean (red diamonds) for each intensity degree; MI–PGA (left) and MI–PGV (right).

One can observe in these graphics that there is an obvious spreading of the PGA and PGV for each degree of intensity, thus one recorded PGM value corresponds to two, three or even four degrees of intensity. Moreover, these ground motion parameters values spreading for certain degrees of intensity has been previously observed in other MI-PGM correlation studies [22–26]. However, the large scattering of PGA and PGV values for each degree of intensity can be explained by nature itself of these two parameters which characterize the seismic ground motion. On the other hand, the macroseismic intensity is estimated based on people's description, subjective sometimes, about the effects of the seismic shaking on the environment and buildings. Therefore, many factors can affect the estimation of intensity for a given location, such as population density, the type and the building vulnerability, as well as the social, cultural and economic environment. Another aspect that concurs to this scattering is that PGM refer only to a maximum value recorded in one point, unlike the macroseismic intensity that refers to the effects (maximum or moderate) produced by the earthquake and observed on a certain area.

Using equations 1 and 2 we have calculated predicted PGA and PGV intervals for each MI degree (Table 2). Since the macroseismic intensities used in this study are only constituted by the integer numbers, PGA and PGV interval limits were obtained after a rounding convention such as values between 5.50 and 6.49 round to intensity VI. In this purpose, Figure 5 shows the results obtained from equations 1 and 2 for intensity values ranging between 5 and 9, and presented in Table 2. The horizontal axis of the graphs plotted in Figure 5, corresponding to the ground motion parameters (PGA and PGV), is expressed in base-10 logarithmic scale.

Table 2

Proposed ranges of PGA and PGV for each MI in Vrancea subcrustal region

Intensity (MSK)	PGA range (cm/sec^2)	PGV range (cm/sec)
V	20.2÷37.3	1.17÷2.59
VI	37.4÷69.2	2.6÷5.75
VII	69.3÷128.5	5.76÷12.75
VIII	128.6÷238.4	12.76÷28.24
IX	238.5÷442.5	28.25÷62.55

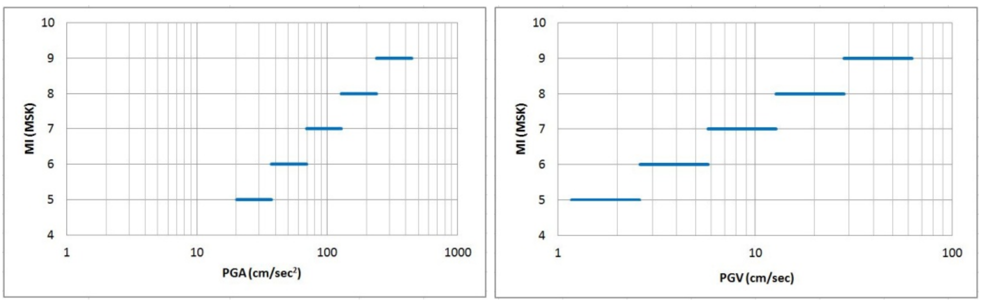

Fig. 5 – Macroseismic intensity with respect to PGA (left) and PGV (right).

4. CONCLUSIONS

The main focus of this paper was the analysis of all the data collected (macroseismic) and recorded (instrumental) during the last 6 significant/strong earthquakes (5.4 < Mw < 7.4) occurred in the Vrancea subcrustal seismic zone between 1977–2009, in order to develop a correlation relationship between observed macroseismic intensity and instrumental ground motion parameters for this seismic region. The main observations may be summarized as follows:

– The use of instrumental data (PGA, PGV, etc.) should be considered as an approximate way of completing the information provided by the macroseismic investigations, keeping in view the fact that the limitation of the territory coverage of instrumentation will exist in the future too, but many more human observers will be out there on the ground and can notice the effects of the earthquake;

– It is obvious that there is a clear increasing tendency of ground motion parameters with intensity, however, there is a significant PGM scatter for a given intensity level – *i.e.* the largest acceleration being observed at MI = VI MSK of 264 cm/s^2, and also for one acceleration value there have been reported sometimes even four different degrees of intensity (PGA = 200 cm/s^2 and MI = VI ÷ IX MSK);

– After the results, we can conclude that such relationships between macroseismic intensity and instrumental ground motion parameters must be obtained on local scales and they must be used in areas with similar geological structure and the same type of buildings;

– In addition to other studies about the MI-PGM correlation, in this study compilation of the data set resulted in 218 pairs from 6 earthquakes are considered, including the events from October 2004 and April 2009. Since the macroseismic intensity value is not directly associated with PGA and PGV values, which are obtained from one point, relationships were obtained by regression between the MI and geometric mean of PGA and PGV for each intensity level. Correlations were developed for the intensity range of $V \leq MI\ (MSK) \leq IX$. After that, we have tested the obtained relations (equations 1 and 2) to find the predicted PGA and PGV intervals for each MI value. The predicted macroseismic intensity values using the peak ground motion parameters are with plus/minus one half a unit most of the time and plus/minus one unit, in general.

Finally, it is important to calibrate the relations used for intensity estimations in such a manner as to provide the best possible correlation with the existing intensity database, obtained on macroseismic criteria. The bottom line, more ground motion records from strong subcrustal earthquakes, and MI values are necessary to refine the results.

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