Near-field strong ground motion records from Vrancea earthquakes

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ABSTRACT:
The seismic events of March 4, 1977 (M_W = 7.4), August 30, 1986 (M_W = 7.1), May 30, 1990 (M_W = 6.9), May 31, 1990 (M_W = 6.4) and October 27, 2004 (M_W = 6.0) represent the latest five major earthquakes produced by the Vrancea subcrustal seismic source. The main focus of this paper is to apply the definitions for near-field conditions with emphasis on Vrancea strong ground motions. The limits of the damage potential parameters used to define near-field conditions from Martinez - Pereira & Bommer (1998) are analyzed for the records produced by Vrancea subcrustal seismic source. Furthermore, a tentative to produce a magnitude-distance space for defining near-field conditions is made, but one should consider, however, the scarcity of available Romanian seismic ground motions recorded at small epicentral distances. Besides the Modified Mercalli Intensity (*MMI*), the Japanese Meteorological Agency Intensity (I_{JMA}) is also used as a parameter for classifying near-field conditions.

Keywords: seismic intensity scale, damage-potential parameters, hypocentral distance, magnitude.

1. INTRODUCTION

As mentioned in several references, such as (Rupakhety, 2008; Moustafa and Takewaki, 2008), the first evidence of the near-field phenomenon was observed by Benioff in the case of the 1952 Kern County earthquake. However, the first engineering evidence of the near-field phenomenon is related to the March 1957 Port Hueneme earthquake (Moustafa, 2010). Housner and Hudson were the first to show that the ground motion of this earthquake recorded in Port Hueneme consisted basically of a single pulse in which all the energy was concentrated (Moustafa, 2010). Thus, Housner and Hudson concluded that the damage pattern of this earthquake was very unusual for shock of magnitude 4.7. Two other seismic events are significant in the study of the near-field strong ground motions: the 1966 Parkfield earthquake and the 1971 San Fernando earthquake (Moustafa and Takewaki, 2008). A comprehensive list of studies related to the elastic or inelastic response of structures subjected to near-field ground motions is presented by (Rupakhety, 2008).
From the engineering point of view, the ground motions capable of producing seismic intensities *MMI* > VIII are of interest (Martinez-Pereira and Bommer, 1998) when studying the near-field effects. By examining strong ground motions recorded during significant seismic events, it can be seen that generally the regions characterized by seismic intensities *MMI* (Modified Mercalli Intensity) > VIII are close to the earthquake focus, in the near-field or near-source region. The Vrancea 1977 earthquake, as well as the Michoacan 1985 earthquake and the Loma Prieta 1989 earthquake are noticeable examples of seismic events which produced strong shaking and the most severe damage at distances of several hundred kilometers from the source. The causes of this phenomenon can be attributed to unusual site conditions (in the case of Mexico-City) or the coincidence of arrival for direct and reflected S-waves as in the case of the Loma Prieta seismic event (Martinez-Pereira and Bommer, 1998).
Among the features which characterize near-field strong ground motions are the long period pulses present in the velocity and displacement time-history, the high ratio of vertical to horizontal

accelerations, directivity effects or fling effects (Martinez-Pereira and Bommer, 1998; Rupakhety, 2008; Elnashai and Papazoglu, 1997). The forward directivity effects are expected to concentrate away from the source in the case of strike-slip faults, while in the case of reverse faulting the effects should be predominant in the region close to the epicentre (Rupakhety, 2008). The period of the pulse increases in proportion with the earthquake magnitude which is related to the fault length (Sommerville, 2003).

Even though there is a great interest from the engineering point of view for near-field seismic motions, there is no clear definition of this term, nor a clear magnitude-distance relation which can classify records as near-field or far-field. A review of several definitions for near-field is given in (Martinez-Pereira and Bommer, 1998; Spyrakos et al., 2008).

In this paper is used the engineering definition of near field from (Martinez-Pereira and Bommer, 1998) and which is based on several damage potential parameters. The methodology has also been applied in (Spyrakos et al., 2008) in the case of strong ground motion records from Greece.

2. METHODOLOGY DESCRIPTION

Martinez-Perreira and Bommer (1998) introduced lower bound values for several damage potential parameters which can be used to select ground motions able to produce seismic intensities $MMI \geq$ VIII. Among the selected parameters are the following: the peak ground acceleration (*PGA*), peak ground velocity (*PGV*), Arias intensity (I_A), cumulative absolute velocity (*CAV*), damage potential parameter I (Fajfar et al., 1990) and the mean root square of the acceleration a_{rms}.

The Arias intensity (Arias, 1970) I_A is computed as:

$$I_A = \frac{\pi}{2g}\int_0^{t_{tot}} a^2(t)dt \tag{1}$$

The cumulative absolute velocity *CAV* (EPRI, 1988) is determined using relation (2):

$$CAV = \int_0^{t_{tot}} |a(t)|dt \tag{2}$$

The damage parameter I proposed in (Fajfar et al, 1990) is computed with relation (3):

$$I = PGV \cdot t_r^{0.25} \tag{3}$$

where t_r is the significant duration of the strong ground motion.

The root mean square acceleration a_{rms} (Bendat and Peirsol, 1971) is determined using the following relation:

$$a_{rms} = \sqrt{\frac{1}{t_2 - t_1}\int_{t_1}^{t_2} a^2(t)dt} \tag{4}$$

where t_1 and t_2 are the limits of the strong shaking part of the record.

The lower-bound values of the above parameters related to a seismic intensity $MMI \geq$ VIII from (Martinez-Perreira and Bommer, 1998) are given in Table 1.

Table 2.1. Lower-bound values for different damage potential parameters for $MMI \geq$ VIII

Parameter	Lower-bound value
PGA	0.2 g
PGV	20 cm/s
I_A	0.4 m/s
CAV	0.3 g·s
I	0.3 m·s$^{0.75}$
a_{rms}	0.5 m/s^2

3. STRONG GROUND MOTION DATABASE

A strong ground motion database of over 130 horizontal components, recorded during 5 intermediate-depth Vrancea earthquakes, has been used for the analyses. The characteristics of the 5 earthquakes (date, epicentre, position, moment magnitude - M_W and focal depth - h are given in Table 3.1.

Table 3.1. Characteristics of the considered earthquakes (Romplus catalogue)

Earthquake date	Lat. N	Long. E	M_W	h (km)
04.03.1977	45.34	26.30	7.4	109
30.08.1986	45.52	26.49	7.1	131
30.05.1990	45.83	26.89	6.9	91
31.05.1990	45.85	26.91	6.4	87
27.04.2004	45.84	26.63	6.0	105

The records' characteristics for each earthquake are given in Table 3.2. The Modified Mercalli Intensity (*MMI*) for each site was taken from various sources, such as (Marmureanu et al., 2011; Böse et al., 2009; Sokolov et al., 2008; Borcia et al. 2010). The Japan Meteorological Agency (JMA) seismic intensity I_{JMA} which represents a numerical intensity based on all three recorded components was also computed for each site. A description of this intensity scale and of the computation methodology can be found in (Shabestari and Yamazaki, 2001; Karim and Yamazaki, 2002).

Table 3.2. Characteristics of the subcrustal Vrancea source ground motions used in this study

Earthquake date	No. of components	Epicentral distance, km	*MMI*	I_{JMA}
04.03.1977	4	101-269	VI-VIII	3.8-5.6
30.08.1986	44	43-181	VI-VIII	3.9-5.4
30.05.1990	52	14-279	V-VII+	4-5.2
31.05.1990	14	13-188	V-VII	3.4-4.8
27.04.2004	22	2-216	V-VI+	3.5-4.9

4. REPRESENTATION OF DAMAGE POTENTIAL PARAMETERS

The distribution of the six damage potential parameters (maximum value, minimum value and mean value) presented in Cap. 2 with respect to both *MMI* and I_{JMA} is shown in Fig. 1 ÷ Fig. 6. The values of the damage potential parameters are computed as the geometrical mean of the values corresponding to the two horizontal components.

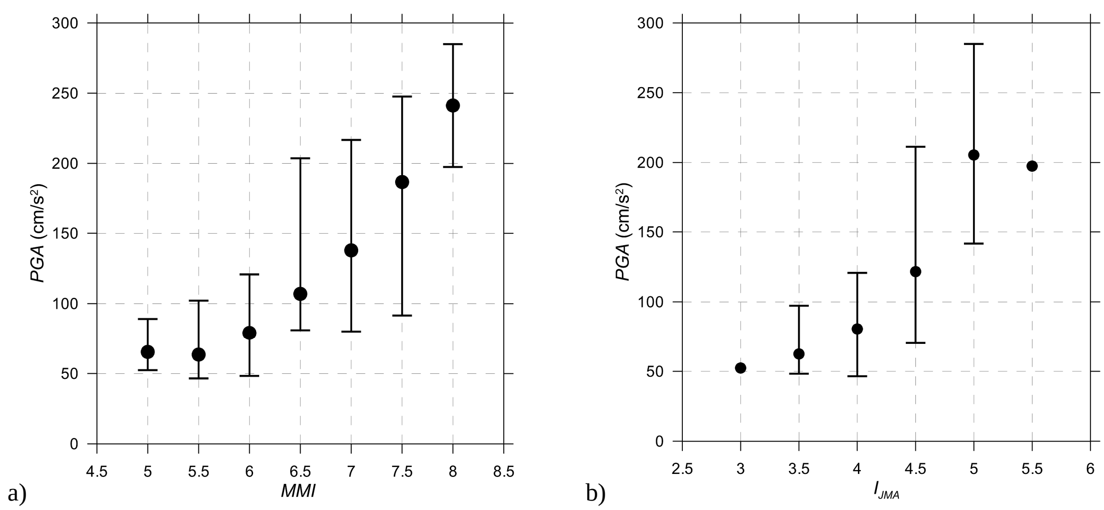
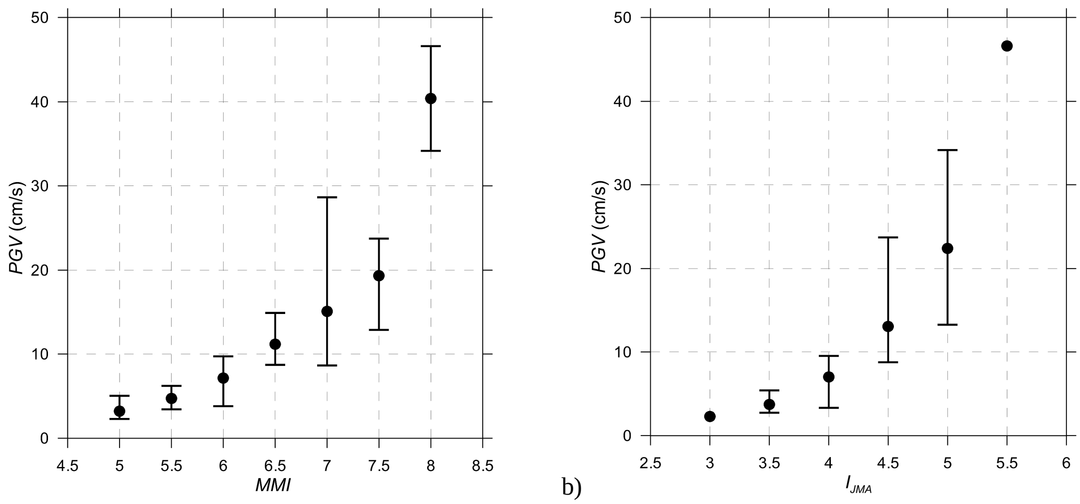
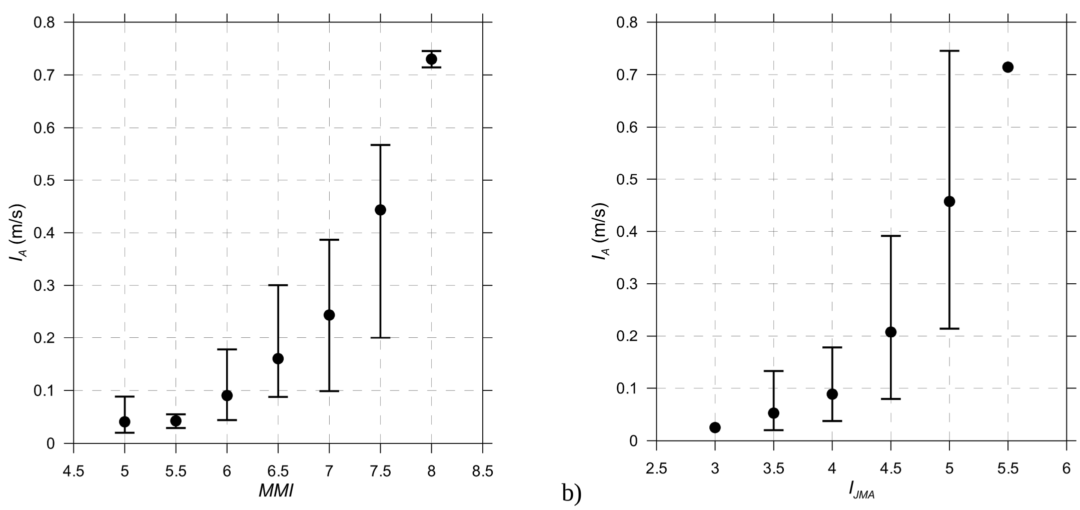


Figure 1. Distribution of the peak ground acceleration (*PGA*) with respect to *MMI* and I_{JMA}



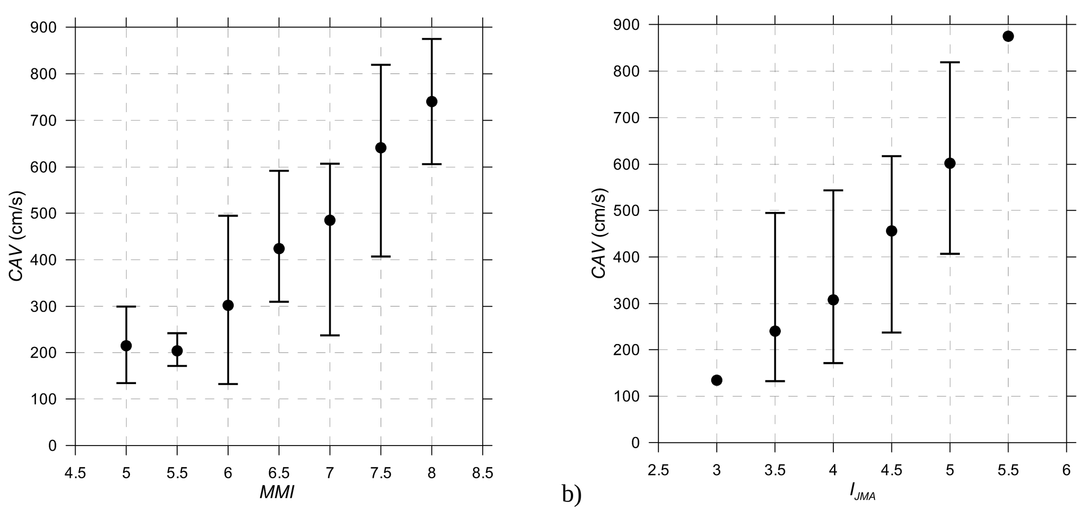
a) b)

Figure 2. Distribution of the peak ground velocity (*PGV*) with respect to *MMI* and I_{JMA}



a) b)

Figure 3. Distribution of the Arias Intensity (I_A) with respect to *MMI* and I_{JMA}



a) b)

Figure 4. Distribution of the cumulative absolute velocity (*CAV*) with respect to *MMI* and I_{JMA}

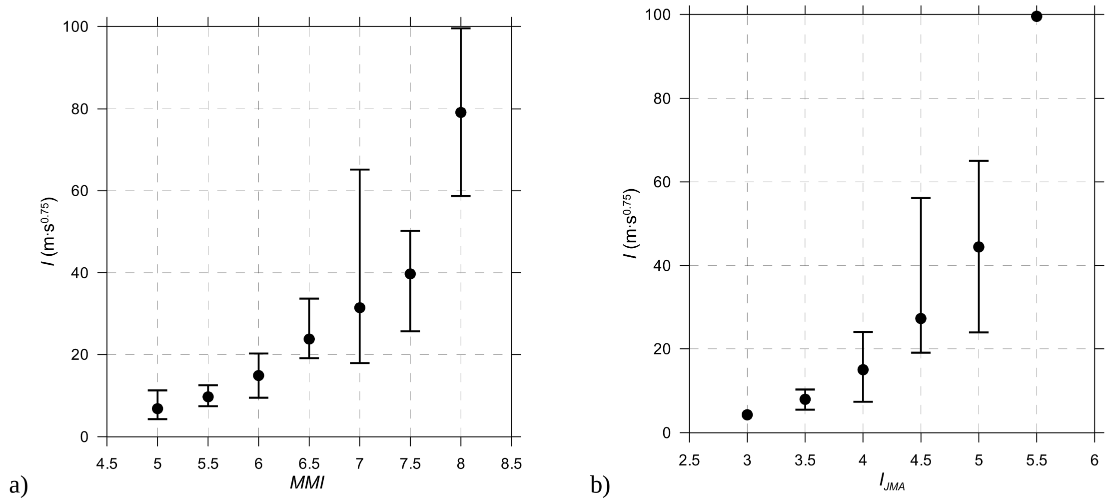


Figure 5. Distribution of the damage parameter I with respect to MMI and I_{JMA}

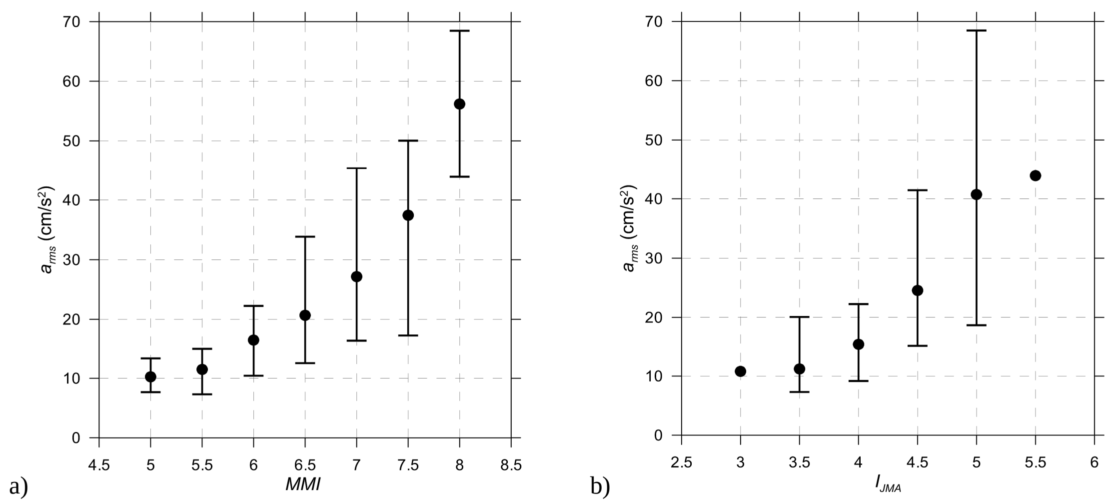


Figure 6. Distribution of the root mean square acceleration (a_{rms}) with respect to MMI and I_{JMA}

The plots presented in the Figures 1 ÷ 6 show a great variability of the results especially for MMI > VI and $I_{JMA} > 4$. However, the increasing median values with intensity of all the 6 analyzed damage-potential parameters is noteworthy.

5. ANALYSIS OF DAMAGE POTENTIAL PARAMETERS

If one considers the limit values of the damage-potential parameters for $MMI \geq$ VIII from Table 2.1, only 2 seismic records can be classified as near-field: the record of the Vrancea 1986 earthquake from Petresti (epicentral distance = 64 km, PGA_{max} = 0.30 g) and the record of the Vrancea 1990 earthquake from Campina (epicentral distance = 120 km, PGA_{max} = 0.27 g). Three other seismic records, including the ground motion recorded during the Vrancea 1977 earthquake at INCERC station in Bucharest fulfil 5 of the 6 criteria. The criterion which appears to be the most selective is root mean square acceleration a_{rms}.

Considering the characteristics of the ground motions recorded during Vrancea earthquakes which were shown in Figures 1 ÷ 6 and the characteristics of the seismic events as well, the lower-bound values proposed by (Martinez-Perreira and Bommer, 1998) for MMI >VIII could be adjusted as shown in Table 4.1. These values are valid only for the areas affected by Vrancea intermediate-depth events.

Table 4.1. Lower-bound values for different damage potential parameters for the classification of near-field strong ground motions (proposal for ground motions induced by the Vrancea subcrustal seismic source)

Parameter	Lower-bound value
PGA	0.2 g
PGV	30 cm/s
I_A	0.7 m/s
CAV	0.6 g·s
I	0.6 m·s$^{0.75}$
a_{rms}	0.4 m/s^2

6. RELATION BETWEEN INTENSITY SCALES

In Figure 7 are shown the histograms of observed MMI and recorded I_{JMA} for the analyzed dataset of ground motions.

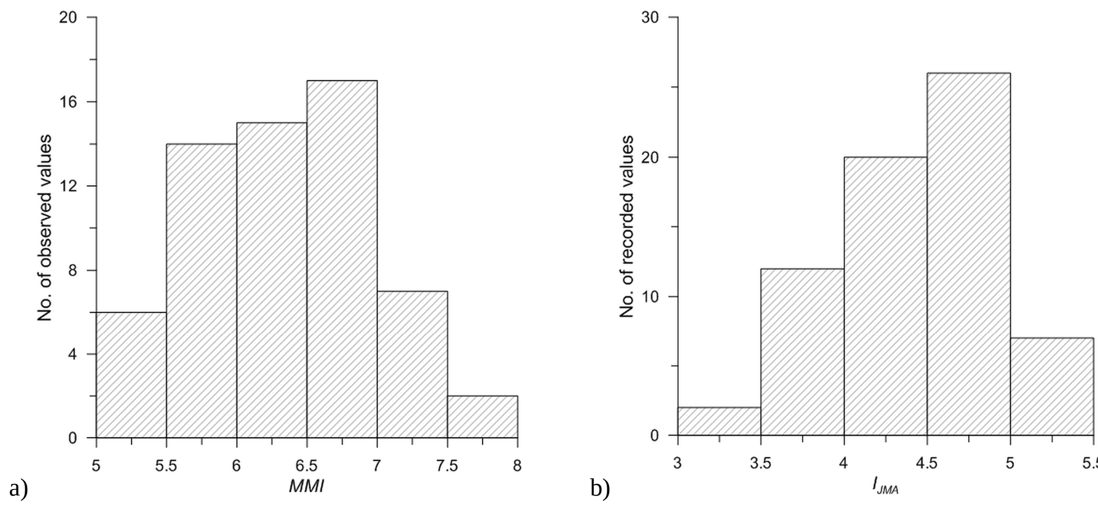


Figure 7. Histograms of observed MMI and recorded I_{JMA}

The distribution shown in Figure 7 is not similar for the two intensity scales. In Figure 8 the relation between observed MMI and recorded I_{JMA} is checked.

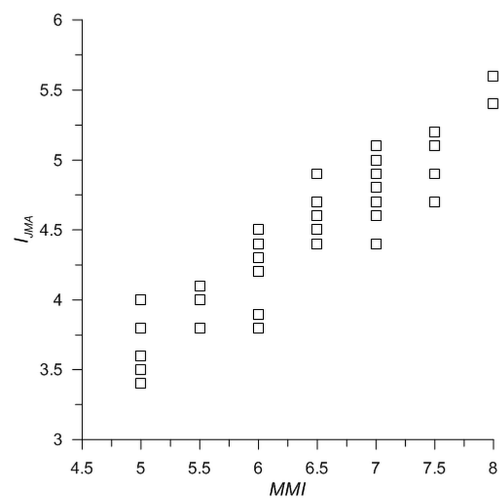


Figure 8. Relation between observed MMI and recorded I_{JMA}

In the case of I_{JMA} the reliability of the results obtained for Vrancea induced strong ground motions is uncertain especially for $I_{JMA} > 5$ (5.5), due to the scarcity of available strong ground motion records.
It is also to be noted that the maximum values of the instrumental seismicity I_{JMA} didn't occur in the regions close to the earthquake epicenter. For instance at Vrancioaia station the maximum value of I_{JMA} is 4.7, recorded during Vrancea 1990 earthquake (epicentral distance = 14 km). The maximum values are recorded at distances ranging between 60 - 120 km, as in the case of the 1990 earthquake. Furthermore, not even in the case of the well instrumented 2004 earthquake, the maximum intensity is not observed in the epicentral region, but at an epicentral distance of 100 km. When evaluating the seismic intensities, one should consider the fact that *MMI* is based on observations, while I_{JMA} is an instrumental intensity, computed using a relation based on Japanese data.
A tentative of a magnitude - distance space for *MMI* = VIII based on the ground motions recorded during Vrancea subcrustal seismic events is shown in Figure 9. Since the line is based on only 2 points, the slope at magnitudes smaller or larger than the considered ones is only assumed to be constant. However, the slope of the line defining the magnitude - distance space might be just as well variable.

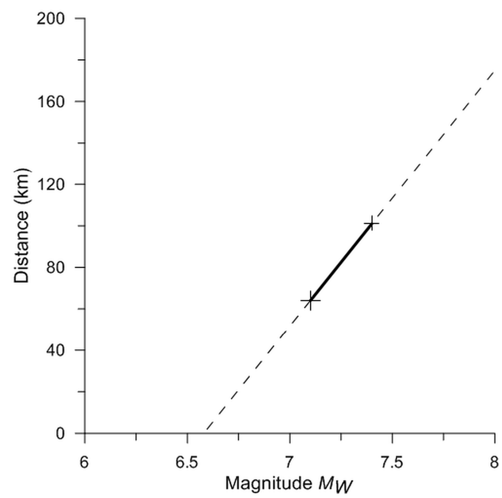


Figure 9. Tentative of a magnitude - distance space for *MMI* = VIII

The lower-limit of the magnitude-distance space is in agreement with the observed data from the recorded earthquakes. The maximum observed intensity of the May, 31st earthquake was *MMI* < VIII, while in the case of the May, 30th earthquake *MMI* = VII. However, in the case of larger magnitude earthquakes, there are no available data to check the relation given in Figure 9.

7. CONCLUSIONS

The main focus of this paper was the analysis of over 60 ground motions (more than 130 horizontal components) recorded during 5 earthquakes produced in the Vrancea subcrustal seismic source in order to check the definitions for near-field motion given by (Martinez-Pereira and Bommer, 1998).
The main observations may summarized as follows:

- The most restrictive parameter for defining near-field ground motions appears to be the root mean square acceleration a_{rms};
- The lower bound values given by (Martinez-Pereira and Bommer, 1998) were adjusted in taking into account the strong ground motions produced by the Vrancea intermediate-depth source. Therefore, the lower bound values are valid only for the particular case of Vrancea induced seismic motions;
- The computed values of the Japan Meteorological Agency (JMA) seismic intensity I_{JMA} show that the maximum intensities were not recorded in the region close to the earthquake epicenter

(e.g. the case of the August 1986, May 1990 and October 2004 earthquakes). This observation is also valid in the case of *MMI*;

- A tentative of a magnitude **-** distance space for defining *MMI* = VIII is proposed. However, due to the lack of data the slope of the line is assumed constant for magnitudes smaller and larger than the considered ones. This relation should be reviewed as soon as new strong ground motion data were made available.

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