SOME DATA AND RESULTS CONCERNING GROUND MOTION IN MOLDOVA DURING RECENT STRONG EARTHQUAKES OF 1986 AND 1990

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ABSTRACT

The instrumental data at hand from Republic Moldova and from two of the accelerographic stations of the network of Romania, located close to the common border, are used in order to compare the features of ground motions and to derive some conclusions on the features of seismicity in Republic Moldova. Response spectra of absolute accelerations and discrete intensity spectra are used for this purpose.

Key-words: strong earthquakes, Vrancea, Republic of Moldova, seismicity, acceleration spectra, intensity spectra

REZUMAT

Datele instrumentale disponibile din Republica Moldova şi din cele două stații accelerografice din rețeaua României, situate în apropierea graniței comune, sunt utilizate pentru a compara caracteristicile mişcării terenului şi pentru a extrage o serie de concluzii referitoare la caracteristicile seismicității Republicii Moldova. În acest scop, sunt utilizate spectrele de răspuns ale accelerațiilor absolute şi spectrele discrete de intensitate.

Cuvinte cheie: seisme puternice, Vrancea, Republica Moldova, seismicitate, spectre de accelerații, spectre de intensitate

1. INTRODUCTION

1.1. General

The Vrancea seismogenic zone is by far the most important source zone in Romania. According to [Bălan & al., 1982], it releases on average more than 95 % of all seismic energy released per century in Romania.

The strong Vrancea earthquakes of 30 August 1986 (M_{GR} = 7.0), 30 May 1990 (M_{GR} = 6.7) and 31 May 1990 (M_{GR} = 6.1) (Table 1) generated strong ground motions for extensive areas of Romania, Republic Moldova and Bulgaria (M_{GR} denotes Gutenberg-Richter magnitudes). Numerous accelerographic records were obtained during these events. The wealth of instrumental data available made it possible to obtain a comprehensive picture of the features of Vrancea earthquakes.

The data at hand make it possible to compare on an instrumental basis the features of ground motions for several sites of Romania and Republic Moldova where accelerographic records were obtained. The object of this paper is represented by such an attempt. Response spectra of absolute accelerations and discrete intensity spectra are used for this purpose.

1.2. Methodological aspects and processing techniques used

The investigation of the features of ground motion and of the reasons for these features was performed using following main approaches:

Table 1.

Characteristics of Vrancea earthquakes referred to

No	Date	Code EQ	Lat. N	Long. E	*h* (km)	M_{GR}	*Mw*
1	1986.08.30	861	45,53	26,47	133	7.0	7.3
2	1990.05.30	901	45,82	26,90	91	6.7	7.0
3	1990.05.31	902	45,83	26,89	79	6.1	6.4

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1. Determining response spectra for strong motion records for 12 horizontal, azimuthally equidistant directions as presented in [Stancu & Borcia, 1999];

2. Calculating corner periods of response spectra;

3. Determining intensity spectra as defined in [Sandi & Floricel, 1998], and briefly summarized also in [Borcia & Sandi, 2010];

4. Determining also of global intensities, on the same basis.

The symbols used in the paper correspond to the entities referred to in Table 2.

The basic definitions of the intensity measures used in the paper [Sandi & Floricel, 1998] are reproduced in Table 3.

Note also that, in addition, following notations were used:

$$EPA = (S_{aa \text{ averaged on } 0.4 \text{ s}})_{max} / 2.5 \quad (1)$$

$$EPV = (S_{rv \text{ averaged on } 0.4 \text{ s}})_{max} / 2.5 \quad (2)$$

$$EPD = (S_{rd \text{ averaged on } 0.4 \text{ s}})_{max} / 2.5 \quad (3)$$

$$T_C = 2\pi \, EPV / EPA \quad (4)$$

$$T_D = 2\pi \, EPD / EPV \quad (5)$$

$$I_S = \log_4 (EPA \times EPV) + 8.0 \quad (6)$$

$$I_{S1} = i_s^{\sim} (0.25 \text{ Hz}, 16.0 \text{ Hz}) \quad (7)$$

$$I_{D1} = i_d^{\sim} (0.25 \text{ Hz}, 16.0 \text{ Hz}) \quad (8)$$

where S_{aa}, S_{rv} and S_{rd} represent the response spectra for absolute accelerations, relative velocities and relative displacements respectively, all of them as functions of period this time, each of them for 5% critical damping, according to the definitions adopted in the code [MTCT, 2006]. Note also that the values *EPA* and *EPV* are somewhat lower than the homologous values *EPAS* or *EPVS*, referred to in Table 2, and this leads to somewhat lower estimates for I_S.

2. BASIC DATA USED

The basic data used, referred to in Table 4, are represented by accelerographic records obtained

Table 2.

System of instrumental criteria for intensity assessment

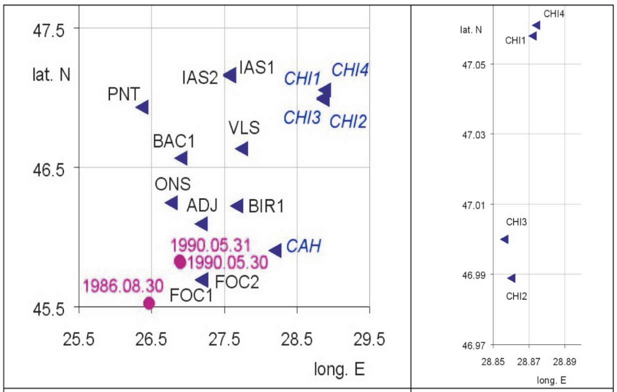
Name	Symbols used for intensities: * global ** related to a frequency *** averaged upon a frequency interval			Source of definition / comments (φ: frequency, Hz)
	*	**	***	
Spectrum based intensities	I_S	i_S (φ)	$i_S^{\sim}$ (φ′, φ′′)	Linear response spectra for absolute accelerations and velocities / use of *EPA*, *EPV*, redefined as *EPAS*, *EPVS* respectively (see Table 2); averaging rules specified
Intensities based on Arias' type integral [Arias, 1970]	I_A	i_d (φ)	$i_d^{\sim}$ (φ′, φ′′)	Quadratic integrals of acceleration of ground (for I_A), or of pendulum of natural frequency φ (for i_d (φ)) / extensible to tensorial definition; averaging rules specified
Intensities based on quadratic integrals of Fourier images	I_F (≡ I_A)	i_f (φ)	$i_f^{\sim}$ (φ′, φ′′)	Quadratic integrals of Fourier image of acceleration (for I_F), or quadratic functions of Fourier images (for i_d (φ)) / extensible to tensorial definition; averaging rules specified.

Table 3.

Basic definitions of I_S, i_s (φ), I_A, and i_d (φ)

Intensity measures	Definitions	Notes
I_S	$I_S = \log_4 (EPAS \times EPVS) + 8.0$	$EPAS = \max_\varphi s_{aa} (\varphi, 0.05) / 2.5$ $EPVS = \max_\varphi s_{va} (\varphi, 0.05) / 2.5$
i_S (φ)	$i_S (\varphi) = \log_4 [s_{aa} (\varphi, 0.05) \times s_{va} (\varphi, 0.05)] + 7.70$	s_{aa} (φ, 0.05): absolute acceleration resp. sp. s_{va}(φ, 0.05): absolute velocity resp. sp.
I_A	$I_A = \log_4\{\int [w_g (t)]^2 \, dt\} + 6.75$	$w_g (t)$ ground motion acceleration
i_d (φ)	$i_d (\varphi) = \log_4\{\int [w_a (t, \varphi, 0.05)]^2 \, dt\} + 5.75$	w_a (t, φ, 0.05): absolute acceleration of pendulum with eigenfrequency φ and 5% critical damping

during the events referred to at the stations of Chişinău and Cahul of Republic Moldova, to which the station VLS1 of Romania, located in the proximity of the previous ones was added. A summary view on the locations of the stations referred to is provided in Figure 1.



a. Map at regional level | b. Map for Chişinău

Fig. 1. Map of instrumental epicenters and of recording stations (belonging to IGGASM [Md] and INCERC [Ro]) in Moldova and Northeastern Romania

3. RESULTS OF PROCESSING

3.1. General data

A summary view of the characteristics of ground motions recorded in Republic Moldova is provided in Table 5. Some of the data presented correspond to the more detailed developments presented in next subsections.

Table 4.

Recording stations referred to and records available

No.	Recording station (belonging to)	Code station	Lat. North	Long. East	1986. 08.30	1990. 05.30	1990. 05.31
1.	Chişinău – Iss1 (IGGASM)	CHI1	47.058	28.872	*		
2.	Chişinău - Iss2 (IGGASM)	CHI2	46.989	28.860		*	*
3.	Chişinău – Iss3 (IGGASM)	CHI3	47.000	28.856		*	*
4.	Chişinău Ul. Dimo (IGGASM)	CHI4	47.061	28.874		*	*
5.	Cahul (IGGASM)	CAH1	45.905	28.200		*	*
6.	Vaslui (INCERC)	VLS1	46.637	27.733	*	*	*

* Available records;
INCERC: National Institute for Building Research, Bucharest, Romania;
IGGASM: Institute of Geology and Seismology, Academy of Sciences of Moldova, Chisinau, Republic Moldova.

Table 5.

Global characteristics of horizontal components of records obtained in Moldova

No	Record	Code Axis	*PGA* m/s^2	*PGV* m/s	*EPA* m/s^2	*EPV* m/s	*Tc* s	I_S	I_{S1}	I_A	I_{D1}
1	861CHI1	l: 11°	1.874	0.0830	1.604	0.0993	0.39	7.59	7.23	7.40	7.38
2	861CHI1	t: 101°	2.118	0.2094	1.578	0.2311	0.92	7.69	7.73	7.43	7.44
3	901CAH	l: 74°	1.264	0.0614	0.844	0.0683	0.51	6.66	6.45	6.94	6.87
4	901CAH	t: 344°	1.354	0.0886	1.366	0.0654	0.30	6.78	6.86	7.25	7.21
5	901CHI2	l: 132°	1.882	0.0528	0.907	0.0409	0.28	6.80	6.54	7.12	6.98
6	901CHI2	t: 42°	1.726	0.0579	0.947	0.0431	0.29	6.84	6.65	7.17	7.05
7	901CHI3	l: 100°	1.213	0.0466	0.679	0.0325	0.30	6.12	6.20	6.80	6.66
8	901CHI3	t: 10°	1.437	0.0389	0.651	0.0243	0.23	6.67	6.25	7.01	6.88
9	901CHI4	l: 0°	0.750	0.0549	0.528	0.0412	0.49	5.77	5.85	6.00	5.92
10	901CHI4	t: 90°	0.810	0.0611	0.722	0.0382	0.33	6.19	6.11	6.23	6.18
11	902CAH	l: 74°	0.944	0.0364	0.635	0.0349	0.35	5.82	5.81	6.14	6.09
12	902CAH	t: 344°	0.560	0.0294	0.453	0.0268	0.37	5.65	5.42	5.77	5.71
13	902CHI2	l: 132°	0.756	0.0598	0.537	0.0478	0.56	6.11	5.92	6.01	5.92
14	902CHI2	t: 42°	0.876	0.0255	0.443	0.0214	0.30	5.70	5.55	5.80	5.67
15	902CHI3	l: 100°	0.534	0.0295	0.327	0.0353	0.68	5.69	5.43	5.73	5.62
16	902CHI3	t: 10°	0.612	0.0293	0.255	0.0319	0.79	5.54	5.13	5.54	5.41
17	902CHI4	l: 0°	0.396	0.0298	0.388	0.0331	0.54	5.18	5.30	5.20	5.18
18	902CHI4	t: 90°	0.569	0.0563	0.382	0.0549	0.90	5.51	5.68	5.39	5.39

l: (longitudinal): first horizontal direction of record;
t: (transversal): second horizontal (orthogonal to the first one) direction of record;
lt: averaging upon two orthogonal horizontal directions; (no index): global intensities;
1: (one): averaging of frequency dependent intensities over the frequency interval (0.25 Hz, 16.0 Hz), according to expressions (7) and (8).

3.2. Response spectra and corner periods

Response spectra for the absolute acceleration S_{aa} (T, n) were determined for 12 horizontal, azimuthally equidistant directions, as adopted in [Stancu & Borcia, 1999] (Figures 2.1, 2.2 and 2.3). This was done for a 5 % critical damping. The availability of response spectra along 12 equidistant directions made it possible to emphasize the differences in different directions of ground motion.

In addition, a comparison is presented in Figure 2.4 between the response spectra of the records obtained on 1986.08.30 at station CHI1 and on 1990.05.31 at station CAH1 and during both events at VLS1 on one hand and the normalized acceleration response spectra specified by the codes in force of Moldova, and of Romania, [MTCT, 2006], respectively.

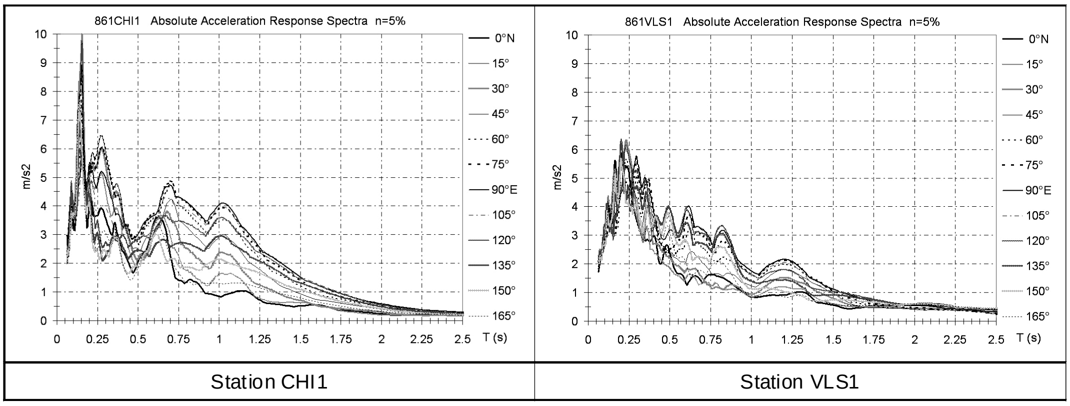


Fig. 2.1. Response spectra for absolute accelerations along 12 equidistant azimuthal directions for records obtained in Chisinau (Md) and Vaslui (Ro) during the 1986 Vrancea earthquake

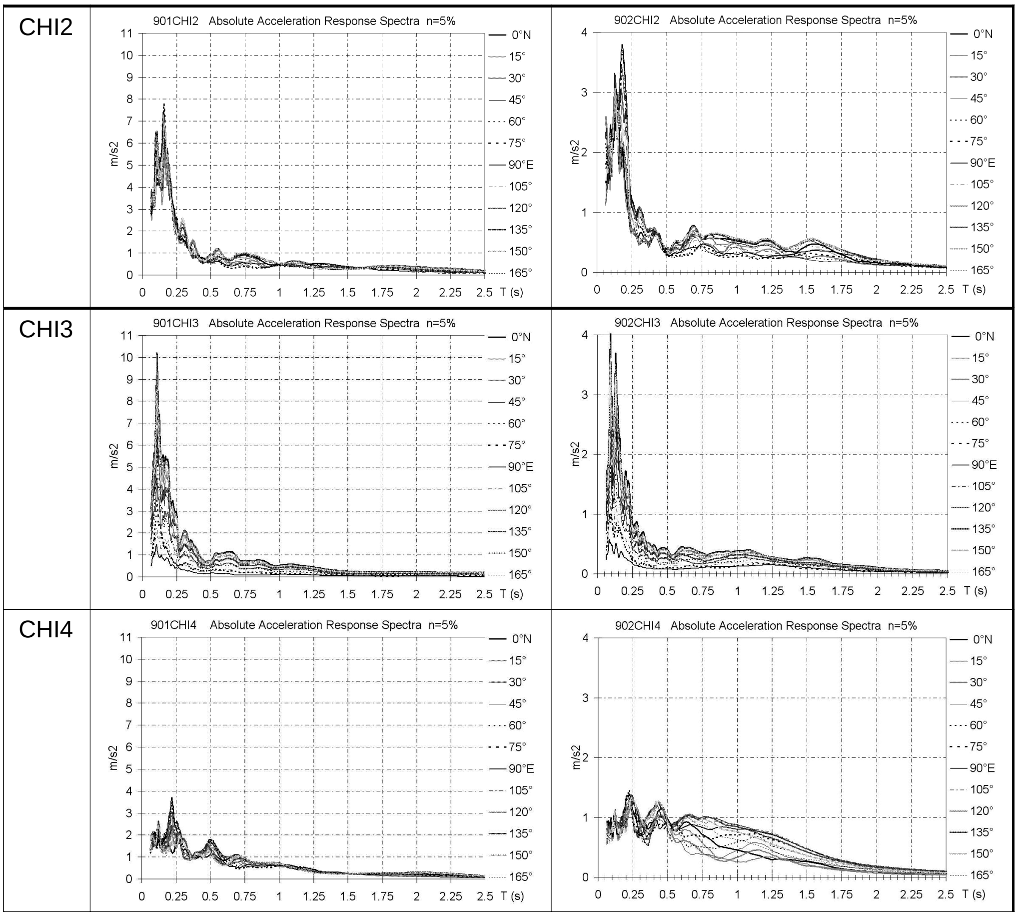


Fig. 2.2. Response spectra for absolute accelerations along 12 equidistant azimuthal directions for records obtained in Chisinau (Md) during the 1990 Vrancea earthquakes

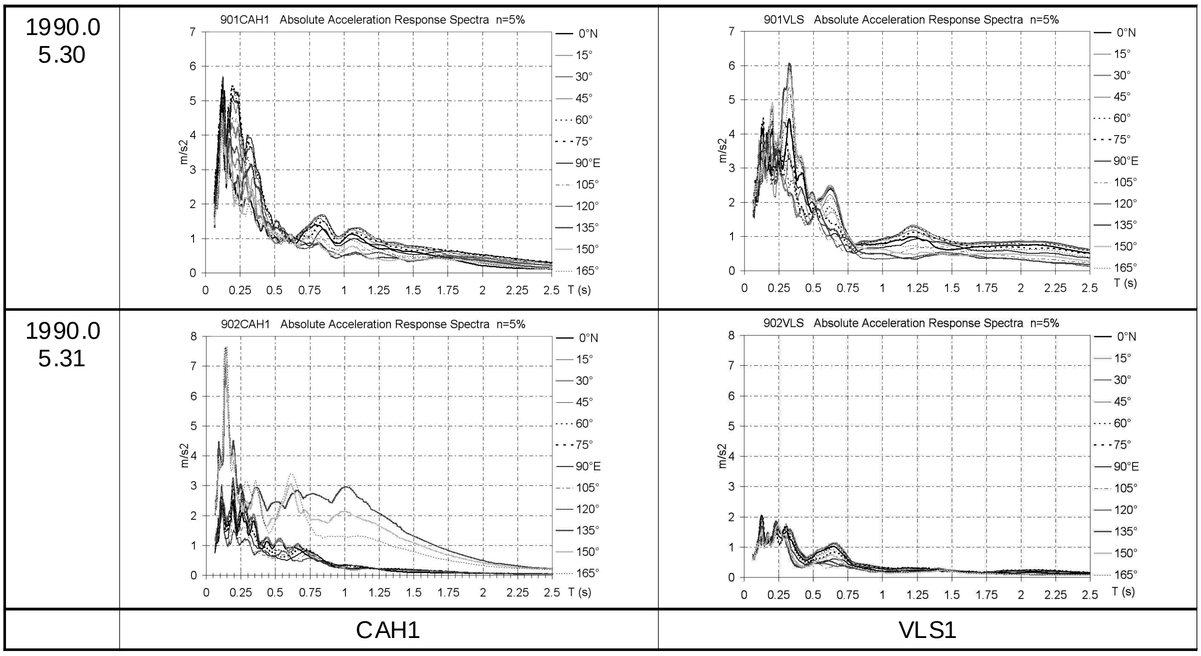


Fig. 2.3. Response spectra for absolute accelerations along 12 equidistant azimuthal directions for records obtained in Cahul (Md) and Vaslui (Ro) during the 1990 Vrancea earthquakes

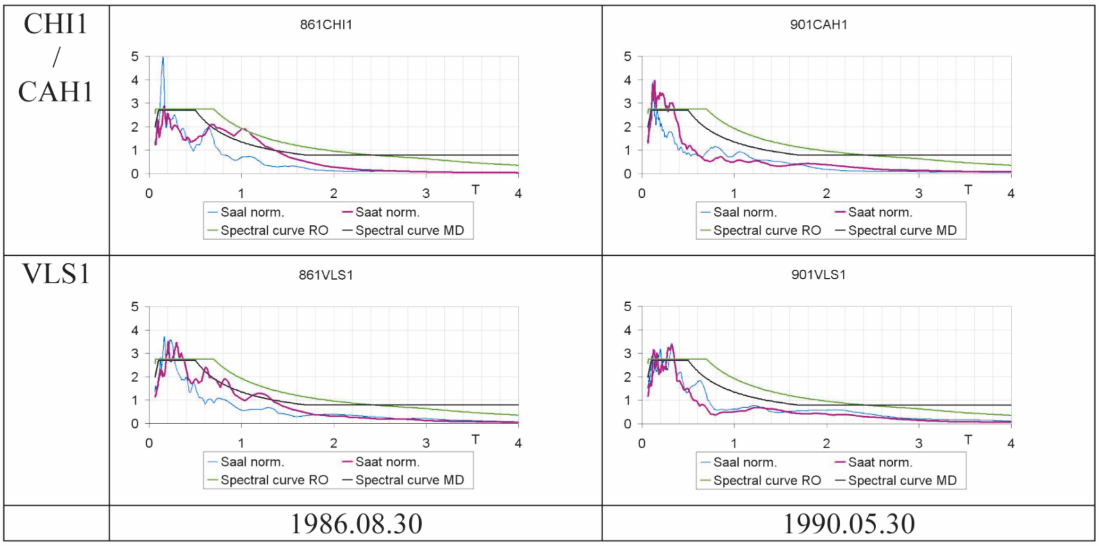


Fig. 2.4. Normalized acceleration response spectra and spectral curves corresponding to the codes in force in the two countries, [MTCT, 2006] for Chisinau (CHI1) and Vaslui (VLS1) for the 1986 Vrancea earthquake (left) and for Cahul (CAH1) and Vaslui (VLS1) for 30 May 1990 Vrancea earthquake (right)

3.3. Intensity Spectra Derived on the Basis of Accelerographic Records

The intensity spectra (discreet, averaged upon 6 dB spectral intervals) presented in Figures 3.1, 3.2 and 3.3 were derived on the basis of accelerographic records. The intensity spectra are organized as follows:

- the abscissa corresponds to lg T;
- the ordinate corresponds to (instrumental) intensity values.

3.4. Comments on the results of processing

3.4.1. On response spectra and corner periods

Attention is to be paid not only to the features of individual motions or spectra, but also to features of sequences of spectra as a whole, which make it possible to emphasize the trends of attenuation and also the trends to stability or to variability (from one

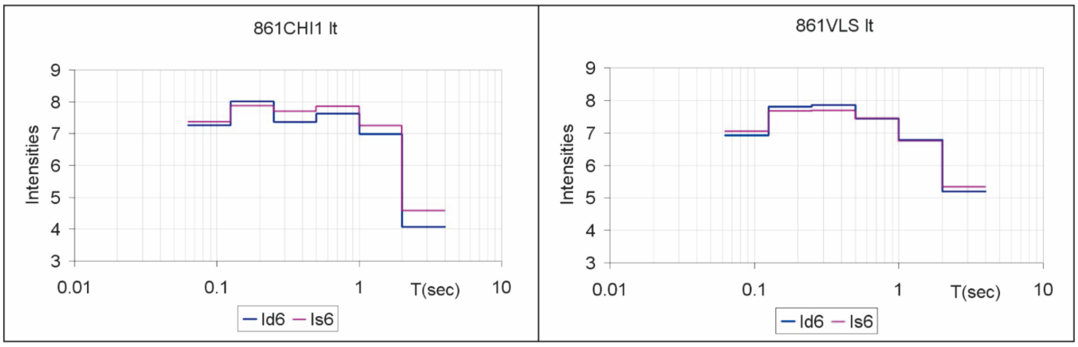


Fig. 3.1. Averaged intensity spectra $i_s^{\sim}$(ϕ', ϕ'') (red) and $i_d^{\sim}$(ϕ', ϕ'') (blue) for 6 dB intervals for Chisinau (recording station CHI1) and Vaslui (VLS1) for the 1986 Vrancea earthquake

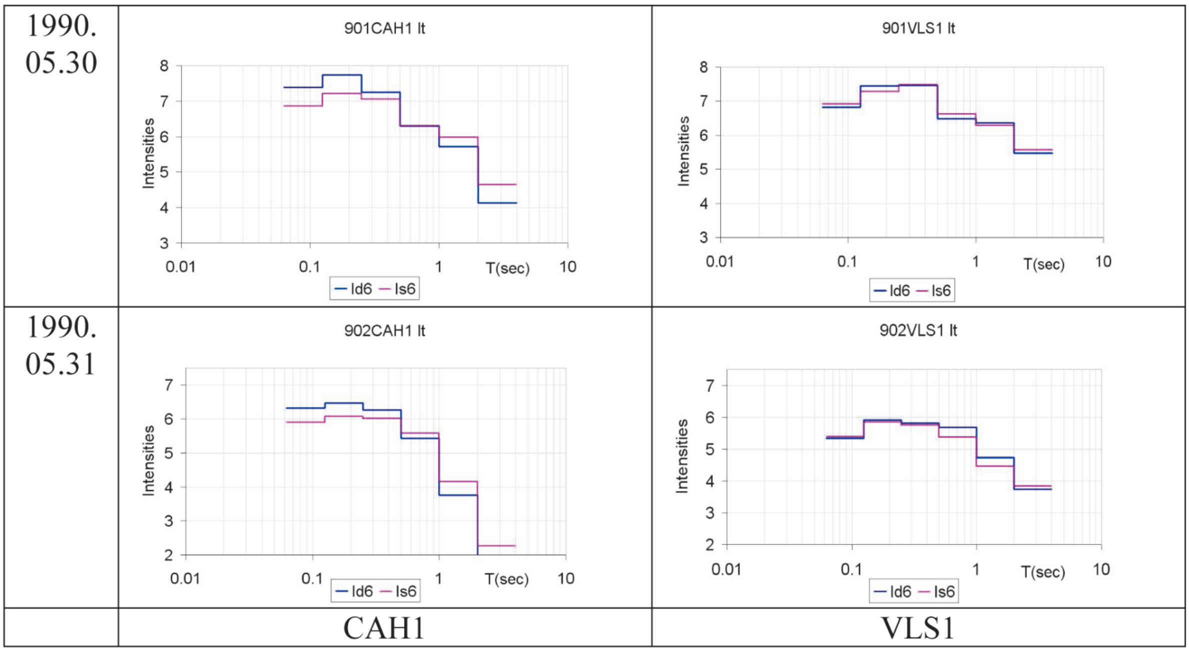


Fig. 3.2. Averaged intensity spectra $i_s^{\sim}$(ϕ', ϕ'') (red) and $i_d^{\sim}$(ϕ', ϕ'') (blue) for 6 dB intervals for Chisinau (recording station CHI2, CHI3, CHI4) for the 1990 Vrancea earthquake

event to another, at a definite location) of the features of ground motion.

Looking at Figure 2.1, combined with Figure 1, it turns out that the response spectrum is more severe for CHI1 than for VLS1, in spite of the fact that the two stations are located along about the same azimuthal direction with respect to the source, while the location of CHI1 is more remote. This difference appears to be obvious especially for relatively long periods, around 1 s.

Looking at Figure 2.2, it turns out that the spectral ordinates were about half as high for the event of 1990.05.31, as compared with homologous results for the event of 1990.05.30, which should be the effect of the features of radiation / attenuation. On the other hand, it turns out that, in case of the latter event, the spectral ordinates become in some way unexpectedly important for CHI4 for the latter event.

Looking at Figure 2.3, it turns out that, while the response spectra were about equally severe for CAH1 and VLS1 in case of the event of 1990.05.30, there is a considerably higher severity for CAH1 in case of the event of 1990.05.31. This is very much in agreement with the fact emphasized in [Sandi & al, 2004] for the stations of Romania, namely the strong trend to radiation towards East in case of the latter event.

The values of corner periods *Tc* in Table 5 are between 0.23 s and 0.92 s, making the value 0.5 s

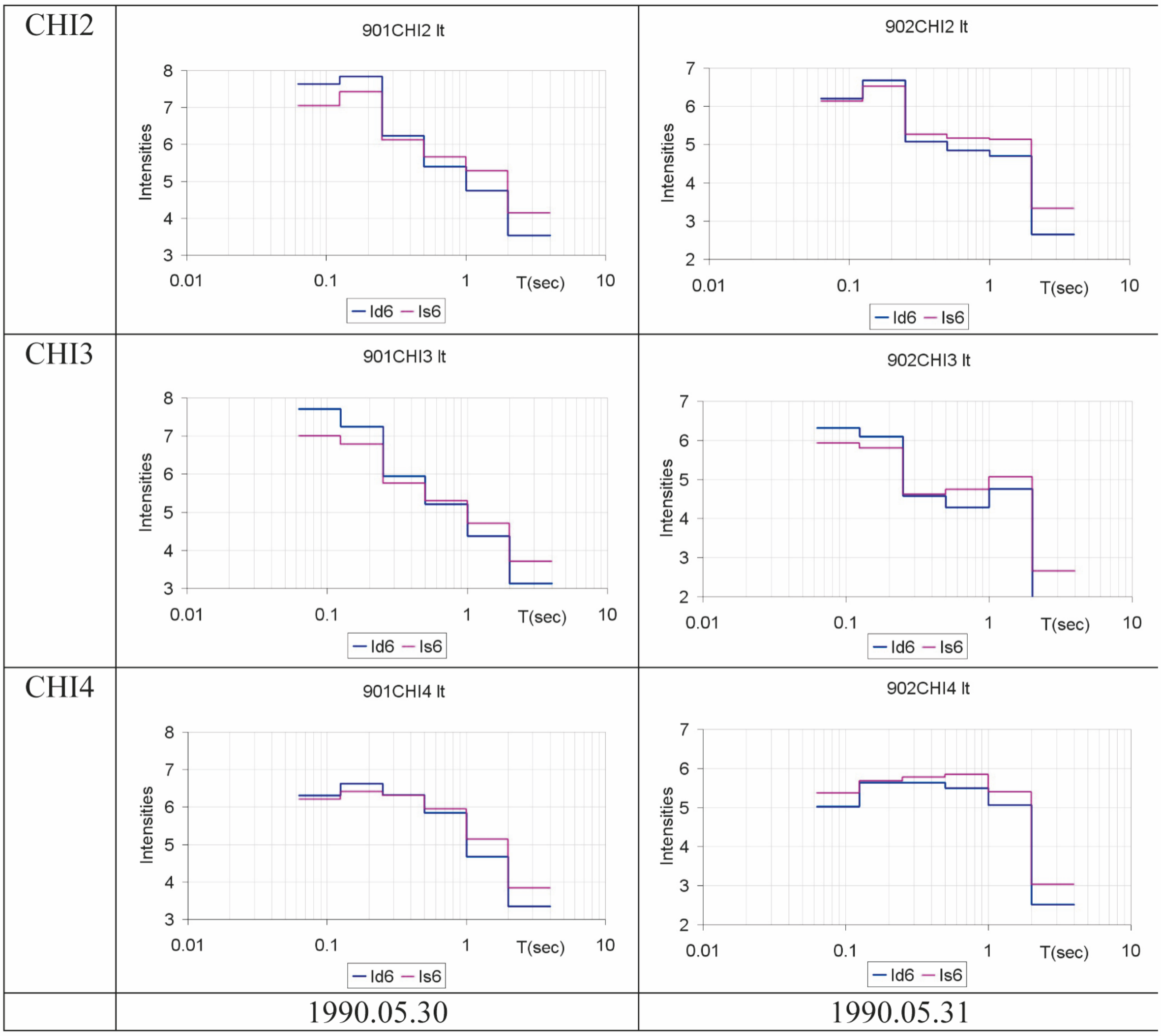


Fig. 3.3. Averaged intensity spectra $i_s^{\sim}$ (φ', φ'') (red) and $i_d^{\sim}$ (φ', φ'') (blue) for 6 dB intervals for Cahul (CAH1) and Vaslui (VLS1) for the 1990 Vrancea earthquake

for the end of the flat portion of the spectral curve corresponding to the code in force in the Republic of Moldova questionable. This fact is illustrated also in Figure 2.4 (left). Table 5 shows a very good correlation between values of Arias intensity I_A and values of intensity based on the destructiveness spectrum averaged over the frequency interval (0.25 Hz, 16.0 Hz), I_{D1}.

In spite of the fact that the ground conditions are the same for all directions of oscillation, there are in some cases important differences between spectral ordinates corresponding to different directions for the same event and place (the extreme ratios of ordinates reach or even exceed, the threshold 3.0 for some oscillation periods as illustrated in Figure 2.1 for the CHI1 station, in Figure 2.2 for the CHI4 station and in Figure 2.3 for the CAH1 station, for the event of 1990.05.31).

3.4.2. On intensities and intensity spectra

A look at Table 5 shows that correlations are strong between the values I_S and I_{S1} on one hand and even stronger between I_A and I_{D1} on the other hand. The correlation is weaker between I_S and I_A, but the individual relative deviations are nevertheless (perhaps with the exception of 901 CHI3 l) lower than the accuracy and certainty with which traditional macroseismic intensities can be estimated.

A look at Figures 3.1, 3.2 and 3.3 makes it possible to express some remarks about the intensity spectra. The two kinds of intensity spectra are well correlated for most of the cases and spectral bands dealt with. It turns out that, when relevant differences appear, the values of $i_s^{\sim}$(φ', φ'') (red) tend to be higher for longest period spectral bands and lower for shortest period spectral bands than $i_d^{\sim}$(φ', φ'') (blue). This may be remarked especially for the stations CHI2 and CAH1. A look at Figure 3.3, e.g., shows that there are differences around 0.6 degree of intensity for intensities averaged over period intervals (0.0625…0.125 s) and (0.125…0.250 s) and differences around -0.9 degree of intensity for (2.0...4.0 s).

A look, especially at Figures 3.2 an 3.3, for the spectral interval ranging from about 0.125 s to about 2.0 s, which is the most significant for the effects upon structures, shows that the intensity spectra strongly depend upon period. This remark warns upon the danger of misestimate of intensities in case one neglects the spectral bands for which the field data sampled during post-earthquake field surveys are.

4. FINAL CONSIDERATIONS

An examination of the strong-motion records available and of the spectra determined indicate that it is particularly important to consider all available data because considering one station or even one event in isolation could lead to unrealistic conclusions. This is why the availability of strong-motion data for several events originating in the same source zone is so important.

An aspect of primary interest for this paper is the fact that for sites CHI1 and CHI4 there was a strong tendency to variability of the spectral contents of ground motion (as illustrated by the response spectra of figures 2.1, 2.2 and 2.3). Explaining the reasons for this is of obvious interest because it is directly connected with the ability to anticipate the spectral contents of future strong ground motions. More in depth analyses should lead to results concerning the relative importance of the features of radiation and of local conditions to this fact.

The two ways of processing instrumental data, namely the determination of response spectra and of intensity spectra, appear to be complementary. The use of both of them appears to be suitable for in depth analyses of ground motion.

Depending on period or frequency interval, there appears to occur frequently a significant variation of the spectral band-related averaged intensities. This provides a picture of the spectral intervals for which the intensities are higher and, consequently, the severity of seismic action appears to be higher. There are differences in outcome if alternative definitions of $i_s^{\sim}(\varphi', \varphi'')$ and $i_d^{\sim}(\varphi', \varphi'')$ are used, but the differences are moderate and definitely less than the possibilities for discrimination provided by the use of macroseismic intensities derived from visual post-earthquake surveys. It is to mention that the instrumental intensities are continuous quantities, differing of standard macroseismic intensity (discrete quantity).

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