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ANALYSIS OF ATTENUATION FOR RECENT VRANCEA INTERMEDIATE DEPTH EARTHQUAKES

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SUMMARY

The paper presents the outcome of attenuation analysis performed for the Vrancea (Romania) earthquakes of 1977.03.04 (M_{GR} = 7.2), 1986.08.30 (M_{GR} = 7.0), 1990.05.30 (M_{GR} = 6.7) and 1990.05.31 (M_{GR} = 6.1). The input data were instrumental. The attenuation analysis was performed in detail, up to the consideration of directional and spectral features. Ground motion parameters alternatively used are defined. The analysis techniques are presented. The results obtained in 1995 are presented for reference. The new results, using a more complete database and more complete analysis techniques, are then presented. They refer to various regression functions, to the outcome of azimuthal Fourier expansion and to the r.m.s. values of various parameters. Results are finally discussed and conclusions are drawn out with respect to methodological aspects and to the features of Vrancea earthquakes.

1. INTRODUCTION

The development of the strong motion array in Romania made it possible to obtain during last years numerous (more than 150) valuable strong motion records during the strong Vrancea earthquakes of 1977.03.04 (M_{GR} = 7.2), 1986.08.30 (M_{GR} = 7.0), 1990.05.30 (M_{GR} = 6.7) and 1990.05.31 (M_{GR} = 6.1). Most of them refer to the ground motion, while the rest are referring to the motion of upper floors of relatively high rise buildings.

The Vrancea intermediate depth seismogenic zone is by far the most important seismogenic zone of Romania, releasing in the average per century more than 95% of the total energy released in Romania [1].

The availability of relatively rich instrumental information contributed considerably to a better understanding of the seismicity of Romania, especially from the viewpoint of the features of Vrancea intermediate depth earthquakes.

To provide some data of interest for the paper, the seismological zonation map, [13] (expressed in terms of *MSK* intensities) is reproduced in Fig. 1, while the maps used for engineering design, [14], are

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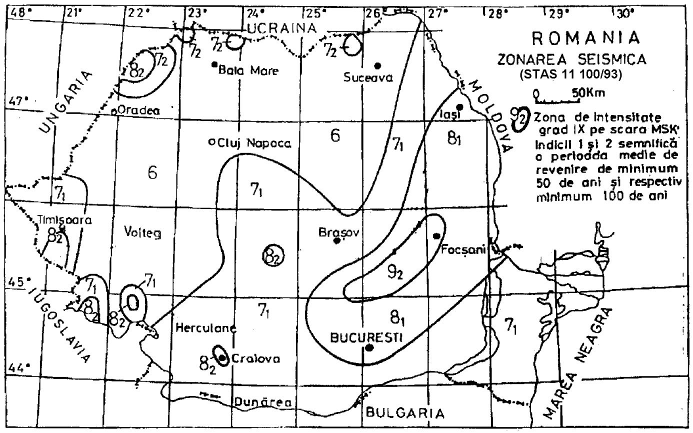


Fig. 1. Seismological zonation map of Romania (expressed in terms of intensities) [13]

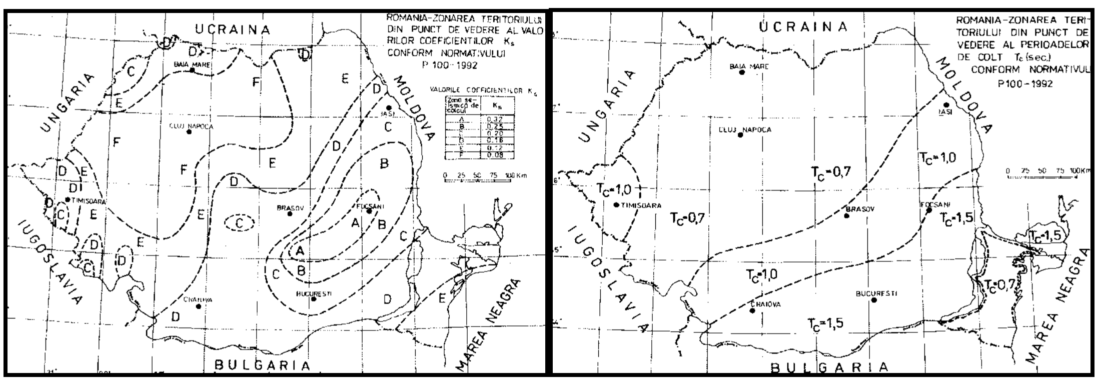
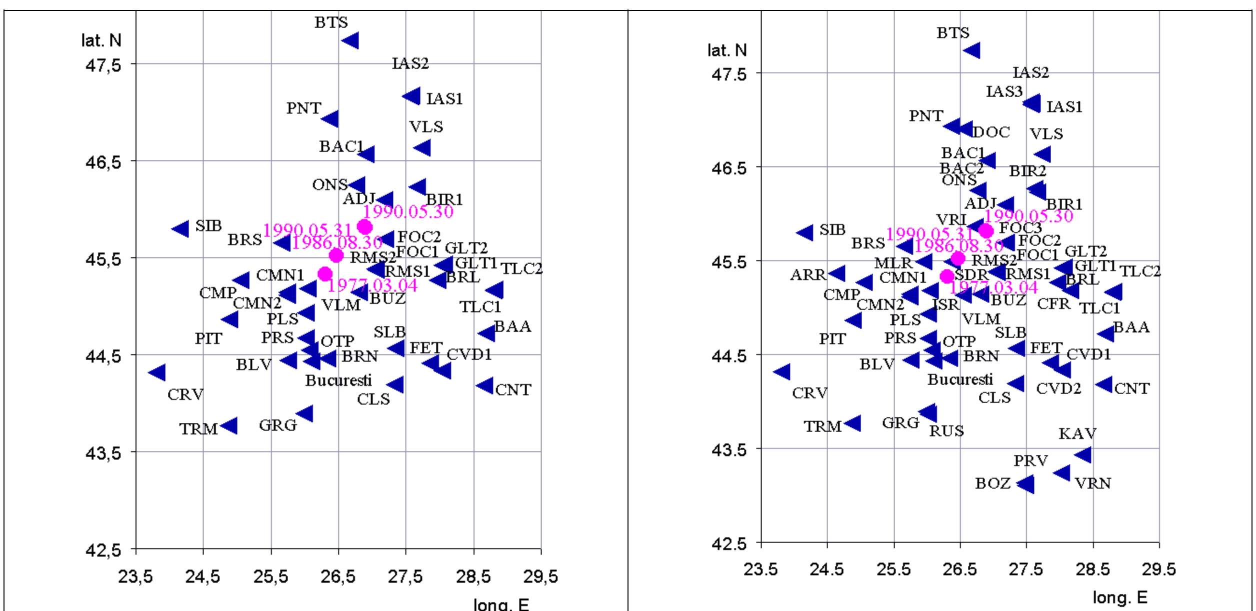


Fig.2. Engineering design zonation maps of Romania (expressed in terms of design parameters) [14]



a) stations considered in 1993 - 1995 [10]	b) stations considered in 2003 - 2004

Fig. 3. Strong motion network of Romania, eastern part (additionally: some stations of Bulgaria)

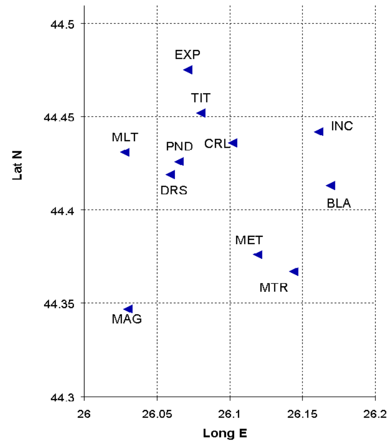


Fig. 4. Strong motion network of the City of Bucharest

reproduced in Fig. 2 (a and b). The maps used for engineering design refer to the basic design coefficient, k_s, and to the velocity/acceleration corner period, T_c, respectively. The concern for their gradual improvement is of obvious importance for engineering design and the results presented in the paper can contribute to achieving this goal.

One of the main aspects of earthquake features is of course the phenomenon of attenuation, which could be examined in depth based on the instrumental information referred to. The paper is devoted essentially to this aspect. The work presented in the paper continues the work initiated in [10], going this time up to the analysis of attenuation in directional and spectral terms.

2. DATABASE USED

The basic data used in view of analyzing the attenuation consisted of the accelerograms having become available subsequently to the earthquakes referred to.

The geographic distribution of accelerographic strong motion stations considered (which cover the eastern part of Romania) is presented in Fig. 3, as follows: in Fig. 3a, stations considered during the analysis completed in 1995 [10]; in Fig. 3b, stations considered more recently. The stations of Fig. 3a pertain to the network of INCERC (National Building Research Institute), while the stations of Fig. 3b pertain also to the networks of INCDFP (National Institute of Earth Physics) and of Bulgaria. A detailing of the network for the City of Bucharest is presented in Fig. 4.

3. METHODOLOGICAL ASPECTS

3.1. Measures of ground motion used

The quantitative ground motion characteristics used throughout the paper are as follows:

- peak ground acceleration, *PGA*:
- peak ground velocity, *PGV*;
- peak ground displacement, *PGD*;
- effective peak acceleration (adapted), *EPAS*;
- effective peak velocity (adapted), *EPVS*;
- global spectrum based intensity, I_S;
- frequency dependent spectrum based intensity, i_s (φ) (φ: frequency, Hz);
- frequency dependent spectrum based intensity, averaged upon a frequency interval (φ', φ''), $i_s^{\sim}$ (φ', φ'').

The characteristics *PGA*, *PGV*, *PGD*, *EPAS* and *EPVS* refer to individual directions each (horizontal motion directions only were used in fact). The characteristics I_S, i_s (φ) and $i_s^{\sim}$ (φ', φ'') may refer to individual directions or to the ensemble of two orthogonal horizontal directions. The definitions of *EPAS*, *EPVS*, I_S, i_s (φ) and $i_s^{\sim}$ (φ', φ'') are as given in [11] (together with definitions of other characteristics, not referred to in this paper), where rules of averaging for two orthogonal horizontal directions and of averaging upon a frequency interval were given too. The calibrations adopted for the constant free terms of the various intensity measures rely on a statistical correlation and regression analysis, aimed at reaching the best fit between the alternative definitions adopted, presented in [11]. Part of the developments of [11] are nevertheless reproduced further on.

The definitions used for *EPAS* and *EPVS* are respectively

$$EPAS = \max_T S_{aa} (\varphi, 0.05) / 2.5 \tag{1a}$$

$$EPVS = \max_T [S_{aa} (\varphi, 0.05) \times T / (2\pi)] / 2.5 \tag{1b}$$

or, alternatively (and better)

$$EPVS' = \max_T S_{va} (\varphi, 0.05) / 2.5 \tag{1b'}$$

where S_{aa} (φ, n) (m/s^2) and S_{va} (φ, n) (m/s) represent response spectra for the absolute acceleration and for the absolute velocity respectively, as functions of the frequency φ and of the fraction of critical damping n.

The definition used for I_S is

$$I_S = \log_4 (EPAS \times EPVS) + 8.0 \tag{2}$$

The rule of averaging i_s for two orthogonal directions (x and y) is

$$I_S = \log_4 (EPAS_x \times EPVS_x + EPAS_y \times EPVS_y) + 7.5 \tag{2'}$$

The definition used for i_s (φ) is

$$i_s (\varphi) = \log_4 [S_{aa} (\varphi, n) \times S_{va} (\varphi, n)] + 7.7 \tag{3}$$

The rule of averaging for two orthogonal directions (x and y) is

$$i_s (\varphi) = \log_4 [S_{aax} (\varphi, n) \times S_{vax} (\varphi, n) + S_{aay} (\varphi, n) \times S_{vay} (\varphi, n)] + 7.2 \tag{3'}$$

The rule of averaging (for a single direction) for an interval of frequencies (φ', φ'') is

$$i_s^{\sim} (\varphi', \varphi'') = \log_4 \{[1./\ln (\varphi''/\varphi')] \times \int_{\varphi'}^{\varphi''} [S_{aa} (\varphi, n) \times S_{va} (\varphi, n)] \, d\varphi / \varphi\} + 7.7 \tag{4}$$

A corresponding rule is adopted when dealing with two orthogonal horizontal directions.

It may be mentioned that a good correlation exists between I_S and macroseismic estimates, [6], and that the frequency related intensities $i_s^{\sim}$ (φ', φ'') are well correlated with the statistical damage spectra presented in [1], which relied on the survey carried out subsequently to the destructive earthquake of 1977.04.03.

3.2. Type of attenuation relations used

The attenuation relations used rely on Blake's relation [2], with some extension introduced in [7], based on data of [1] concerning the relationship between epicentral intensity and magnitude. The attenuation relations used consider a lumped source, located at a depth h (km). Two steps are considered:

determination of the expected epicentral intensity $I_0^{\sim}$;

determination of the expected intensity decrease $\Delta I^{\sim}$ corresponding to the epicentral distance r (km).

The severity of an earthquake is quantified by the Gutenberg – Richter magnitude, M_{GR}, while the severity of ground motion is quantified in terms of intensities, which are considered as I_S, according to relations (2), (2'); they are practically equivalent [6] (with the approximation of rounding up) with *MSK* [5] or *EMS* [4] intensities.

The expected epicentral intensity is given by the expression

$$I_0^{\sim} = (1.3 + 0.25 \times \lg h)\, M_{GR} - (3. \times \lg h - 2.) \tag{5}$$

(lg: decimal logarithm; h(km): source depth) while the expected intensity reduction is given by the expression

$$\Delta I^{\sim} = b\, \rho \tag{6}$$

The coefficients b and ρ were defined as

$$b = (3.0 + 1.5 \lg h) \tag{7a}$$

$$\rho = \lg\, [(1.0 + r^2 / h^2)^{1/2}] \tag{7b}$$

The expected intensity at a site A, $I_A^{\sim}$, is thus obtained as

$$I_A^{\sim} = I_0^{\sim} - \Delta I^{\sim} \tag{8}$$

A recalibration of $I_0^{\sim}$ and b for the various events of Romania referred to on the basis of instrumental information at hand is discussed further on.

3.3. Attenuation analysis

The attenuation analysis was performed (separately for each of the events of 1986.08.30 <M_{GR} = 7.0, h = 133 km>, 1990.05.30 <M_{GR} = 6.7, h = 89 km> and 1990.05.31 <M_{GR} = 6.1, h = 79 km>, for which rich instrumental information was at hand) stepwise, as follows:

determination of regression functions homologous to expression (8), irrespective of direction and frequency band;

determination of directionality characteristics on the basis of Fourier analysis with respect to the azimuthal angle (measured clockwise from N) related to the epicentre;

determination of directionality characteristics for various frequency bands.

Given the fact that the r.m.s. deviations with respect to the regression functions determined were generally the smallest for the parameter I_S, it was found preferable to refer the Fourier analysis with respect to the azimuthal angle primarily to this latter parameter. In case *"i"* is the index of recording stations and I_{Si} is the spectrum based intensity determined for the geographic point referred to, the values $I_{Si}\,(\rho_i, \alpha_i)$ were intended to be expressed as

$$I_{Si}\,(\rho_i, \alpha_i) \approx I_S^{\sim}\,(\rho_i) + \Sigma_n\,(a_n \cos n\alpha_i + b_n \sin n\alpha_I) \quad (n = 1, 2, 3\ldots) \tag{9}$$

where $I_S^{\sim}(\rho_i)$ is the expression obtained from regression analysis irrespective of direction. Since a complete condition of minimization of errors for the Fourier analysis would have been laborious, a simplified condition was adopted for determining the Fourier coefficients:

$$E_n = \Sigma_i \,[\Delta I_{Si} - (a_n \cos n\alpha_i + b_n \sin n\alpha_i)]^2 = \text{min.} \tag{10}$$

where ΔI_{Si} is the difference

$$\Delta I_{Si} = I_{Si} - I_S^{\sim}(\rho_i) \tag{11}$$

The partial derivatives of E_n (10) with respect to a_n and b_n led to the linear conditions

$$\partial E_n / \partial a_n = \Sigma_i \,[\Delta I_{Si} - (a_n \cos n\alpha_i + b_n \sin n\alpha_i)] \cos n\alpha_i = 0 \tag{12a}$$

$$\partial E_n / \partial b_n = \Sigma_i \,[\Delta I_{Si} - (a_n \cos n\alpha_i + b_n \sin n\alpha_i)] \sin n\alpha_i = 0 \tag{12b}$$

with the solution

$$a_n = (2 / \Delta) \,\{[\Sigma_i (1 - \cos 2n\alpha_i)] \,(\Sigma_i \,\Delta I_{Si} \cos n\alpha_i) - (\Sigma_i \sin 2n\alpha_i) \,(\Sigma_i \,\Delta I_{Si} \sin n\alpha_I)\} \tag{13a}$$

$$b_n = (2 / \Delta) \,\{[- (\Sigma_i \sin 2n\alpha_i) \,(\Sigma_i \,\Delta I_{Si} \cos n\alpha_i)] + [\Sigma_i (1 + \cos 2n\alpha_i)] \,(\Sigma_i \,\Delta I_{Si} \sin n\alpha_i)]\} \tag{13b}$$

where

$$\Delta = [\Sigma_i (1 + \cos 2n\alpha_i)] \,[\Sigma_i (1 - \cos 2n\alpha_i)] - [\Sigma_i \sin 2n\alpha_I]^2 \tag{14}$$

3.4. Addenda

The attenuation analysis carried out in spectral terms was related in principle to the 36 dB frequency band (0.25 Hz, 16.0 Hz), adopted as reference, divided into six 6 dB subintervals:

- (0.25 Hz, 0.5 Hz), referred to as subinterval 61;
- (0.5 Hz, 1.0 Hz), referred to as subinterval 62;
- (1.0 Hz, 2.0 Hz), referred to as subinterval 63;
- (2.0 Hz, 4.0 Hz), referred to as subinterval 64;
- (4.0 Hz, 8.0 Hz), referred to as subinterval 65;
- (8.0 Hz, 16.0 Hz), referred to as subinterval 66.

Out of these, results were considered relevant for subintervals 62 to 65, and presented further on.

The attenuation analysis carried out in directional terms was expressed in graphic terms by means of the epicentral distances at which the intensities 7.0, 6.0 and 5.0 respectively, are expected to be reached in each azimuthal direction.

4. PREVIOUS RESULTS

The results of a first period of analysis activity were presented in [10]. The input data were to some extent different at that time (data for less stations, as in Fig. 3a, different accelerogram processing techniques). A summary view of the results of that period is provided in Table 1.

TABLE 1
OUTCOME OF STATISTICAL ANALYSIS OF INSTRUMENTAL DATA PRESENTED IN [10]

Event	Parameters									
	Average attenuation of I_S	R. M. S. values of ground motion parameters						Fourier coefficients for azimuthal I_S distribution		Dominant radiation azimuth for I_S
	$I_0^{\sim} - b\,\rho$	$\log_2$ *PGA*	$\log_2$ *PGV*	$\log_2$ *PGD*	$\log_2$ *EPAS*	$\log_2$ *EPVS*	I_S	a_1 / b_1	a_2 / b_2	
1986.08.30	7.7 – 7.6 ρ	0.925	0.999	1.025	0.836	1.012	0.873	-0.09 -0.01	0.14 0.23	*N 59°E*
1990.05.30	7.2 – 2.1 ρ	0.662	0.790	0.901	0.653	0.735	0.588	-0.03 0.09	0.24 -0.08	*N 161°E*
1990.05.31	5.9 – 2.6 ρ	0.910	0.916	0.756	0.883	0.911	0.584	0.01 0.63	-0.16 -0.47	*N 71°E*

The examination of the results presented makes it possible to emphasize following features of the attenuation phenomenon:

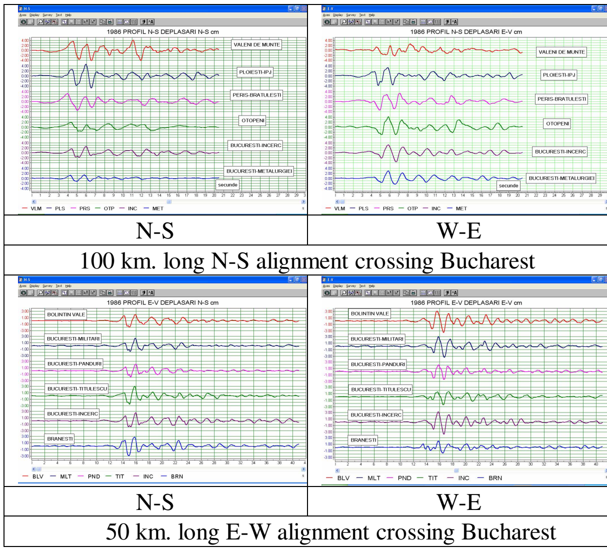
- unexpectedly (since the source was deeper), the attenuation was faster for the event of 1986.08.30 (h = 133 km) than for the events of 1990.05.30 (h = 89 km) and 1990.05.31 (h = 79 km);
- the scatter of various parameters, expressed in units that are comparable with intensity, was high, ranging for the various parameters from about 0.6 to 1.0 intensity units;
- the general scatter tendency (expressed in terms of the comparable units referred to) tended to be highest for peak ground motion parameters *PGA*, *PGV* and *PGD*¸ lower for peak spectral values *EPAS* and *EPVS* and lowest for the intensity I_S;
- the directionality of radiation was strong in all cases (see Fourier coefficients a_2 and b_2);
- while the radiation tended to be rather symmetrical for the first two events, it was strongly non-symmetrical for the last one (see the relatively high value b_1 = 0.63, which meant strong deviation to the East of the macroseismic epicentre);
- the radiation directionality was different for the three events considered: approximately NE-SW on 1986.08.30 (as observed on macroseismic basis for the destructive events of 1940.11.10 <M_{GR} = 7.4> and of 1977.03.04 <M_{GR} = 7.2> too), N-S on 1990.05.30 and E on 1990.05.31).

5. NEW RESULTS

Before presenting proper data on attenuation analysis, it is interesting to present displacement seismograms along two alignments crossing Bucharest, oriented N – S and E – W respectively. They are related to the events of 1986.08.30 (Fig. 5) and 1990.05.30 (Fig. 6) respectively. It may be remarked that the similarity of displacement seismograms for all events, alignments and directions, was unexpectedly strong.

The geographic coordinates of the stations considered are given in Table 2, together with coordinates of other stations referred to subsequently.

The results obtained during the more recent statistical analysis activities are represented first *in graphic terms*, as follows:



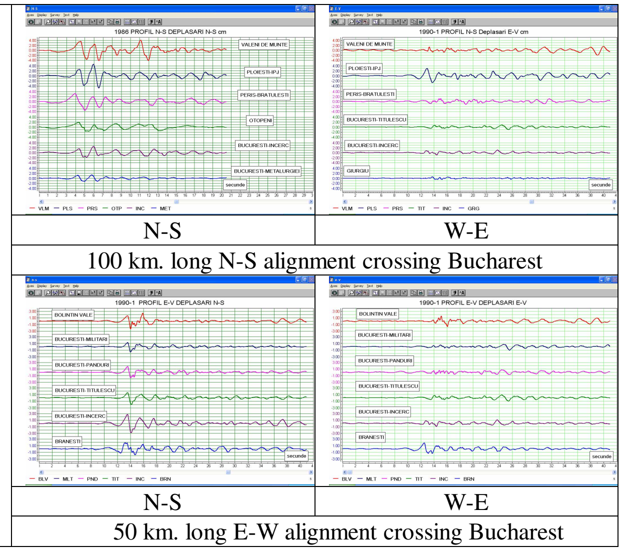


Fig. 5. Displacement seismograms for event of 1986.08.30

Fig. 6. Displacement seismograms for event of 1990.05.30

TABLE 2
GEOGRAPHIC COORDINATES OF STATIONS REFERRED TO IN FIGURES 5 AND 6

No. crt.	Location of station	Lat. North	Long. East	Symbol	1986. 08.30	1990. 05.30	1990. 05.31
1.	Baia-Tulcea	44.723	28.679	BAA	*	*	*
2.	Bârlad	46.228	27.666	BIR1	*	*	*
3.	Bucharest - Balta Albă (s)	44.413	26.169	BLA	*	*	*
4.	Bolintin Vale	44.444	25.757	BLV	*	*	*
5.	Brăneşti	45.269	27.966	BRN	*	*	*
6.	Buzău - Cartier Micro (s)	45.147	26.809	BUZ		*	*
7.	Câmpina - Centre	45.119	25.736	CMN1		*	*
8.	Bucharest - Carlton (s)	44.436	26.102	CRL	*	*	*
9.	Cernavodă-Centru	44.340	28.030	CVD1	*	*	*
10.	Bucharest - Drumul Sării	44.419	26.059	DRS		*	*
11.	Focşani - Centre	45.693	27.192	FOC2	*	*	*
12.	Giurgiu - Police	43.893	25.982	GRG		*	*
13.	Bucharest - INCERC	44.442	26.161	INC	*	*	
14.	Bucharest - Met. Berceni	44.376	26.119	MET	*	*	*
15.	Bucharest -Militari	44.431	26.028	MLT	*	*	
16.	Bucharest-Metro IMGB	44.367	26.144	MTR	*	*	*
17.	Oneşti - Centre	46.250	26.762	ONS	*	*	*
18.	Otopeni	44.549	26.071	OTP	*		
19.	Ploieşti (s)	44.930	26.020	PLS	*	*	*
20.	Bucharest - Panduri	44.426	26.065	PND	*	*	*
21.	Periş - Brătuleşti	44.676	26.019	PRS	*	*	
22.	Râmnicul Sărat (school)	45.380	27.040	RMS2	*	*	*
23.	Bucharest-Titulescu	44.452	26.080	TIT	*	*	*
24.	Vălenii de Munte	45.183	26.038	VLM	*	*	*
25.	Vaslui	46.637	27.733	VLS	*	*	*

Note: *: records obtained (for Bucharest – INCERC: additionally, a record on 1977.03.04)

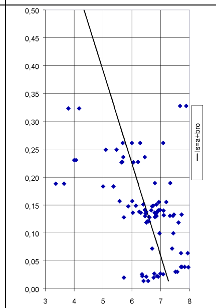
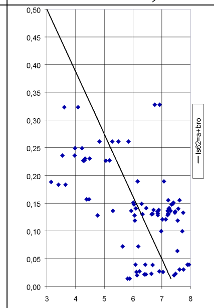
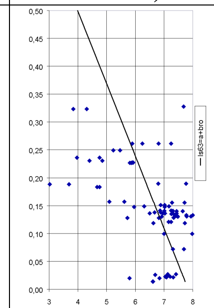
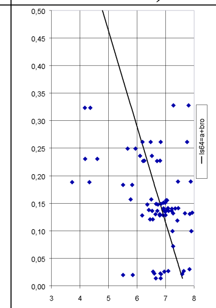
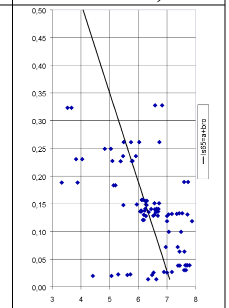
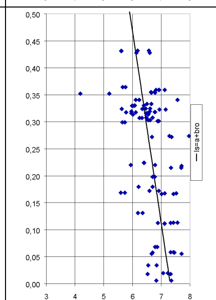
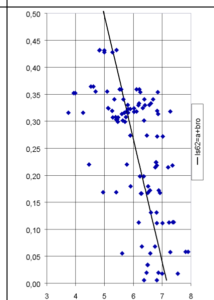
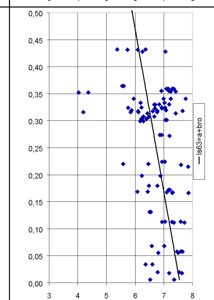
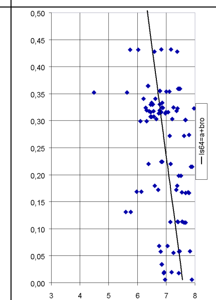
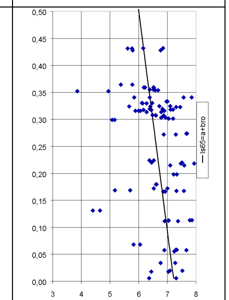
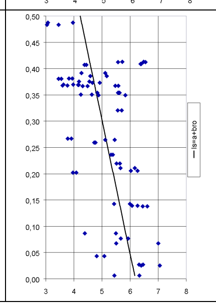
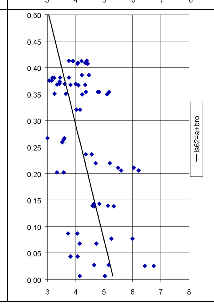
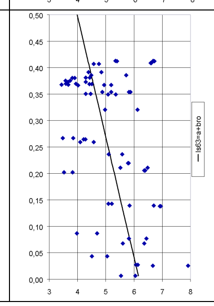
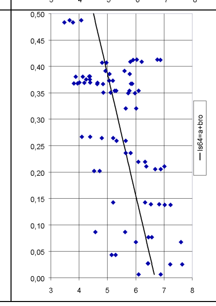
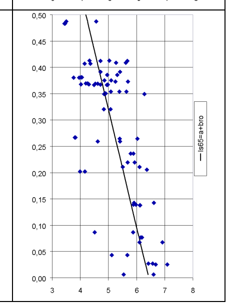
	$\boldsymbol{I_S}$	$i_s^{\sim}{}_{62}$ (0.5 Hz, 1.0 Hz)	$i_s^{\sim}{}_{63}$ (1.0 Hz, 2.0 Hz)	$i_s^{\sim}{}_{64}$ (2.0 Hz, 4.0 Hz)	$i_s^{\sim}{}_{65}$ (4.0 Hz, 8.0 Hz)
1986.08.30, $M_{GR} = 7.0$					
1990.05.30, $M_{GR} = 6.7$					
1990.05.31, $M_{GR} = 6.1$					

Fig. 7. Regression lines for various events and frequency bands

a) presentation irrespective of directionality (in each case, the regression line of one of the parameters referred to below, against the non-dimensional epicentral distance ρ, represented as ordinate, is presented), as follows: presentations, separately for the three events referred to, in Fig. 7: regression lines for abscissae I_S and for $i_s^{\sim}{}_{62,}$, $i_s^{\sim}{}_{63}$, $i_s^{\sim}{}_{64}$ and $i_s^{\sim}{}_{65}$ respectively (using notations as referred to in subsection 2.4), in each case;
b) results of directionality analysis, in Fig.'s 8a and 8b, in terms of curves representing the epicentral distances where the intensities 7.0, 6.0 and 5.0 are expected to be reached, presented at alternative scales, as follows:
- in Figure 8a, using different scales, in order to best visualize each of the plots;
- in Figure 8b, presenting the plots up to a common radius of 1000 km.

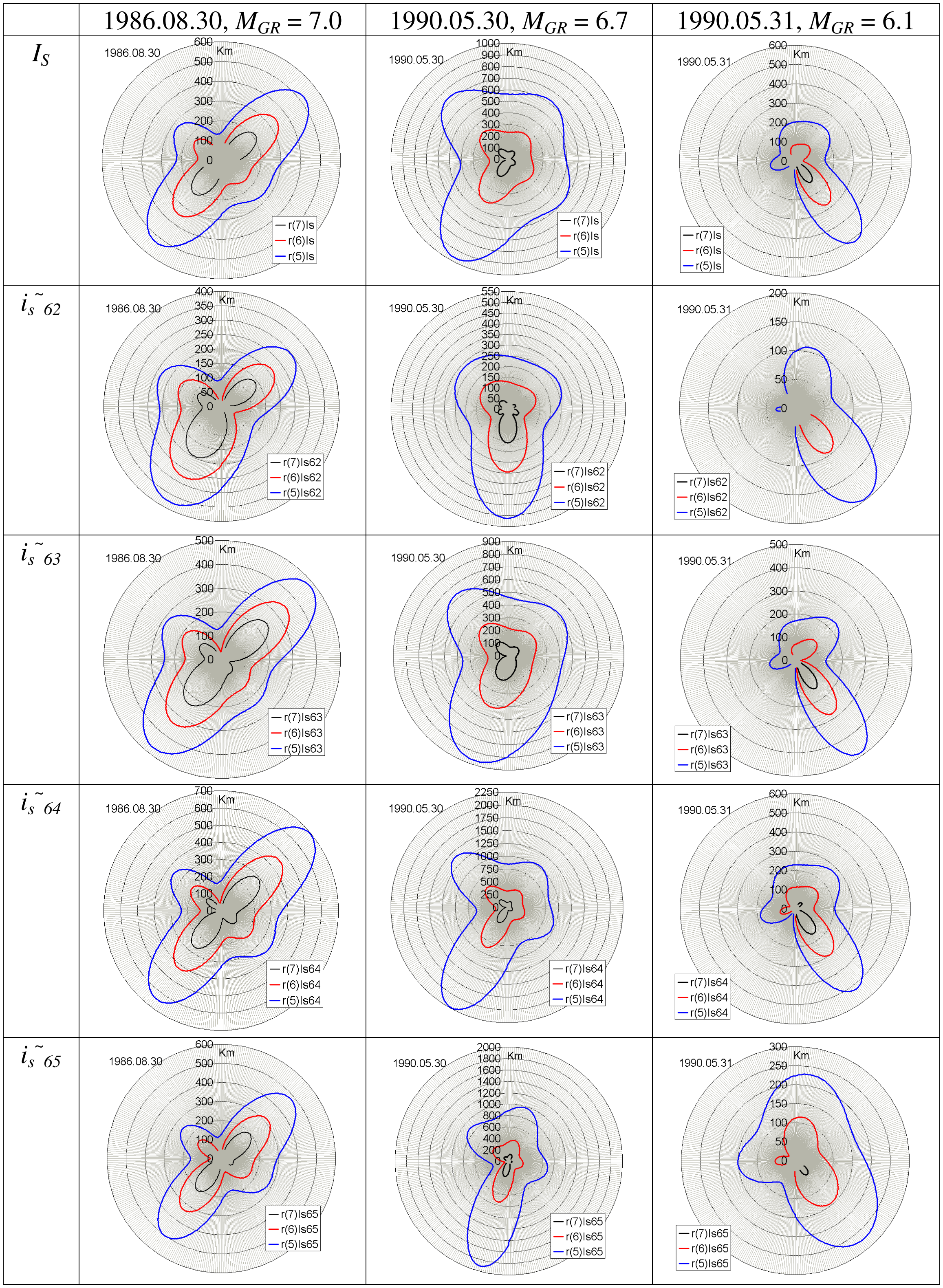


Fig. 8a. Directionality of attenuation, for various events and frequency bands
(best visualization)

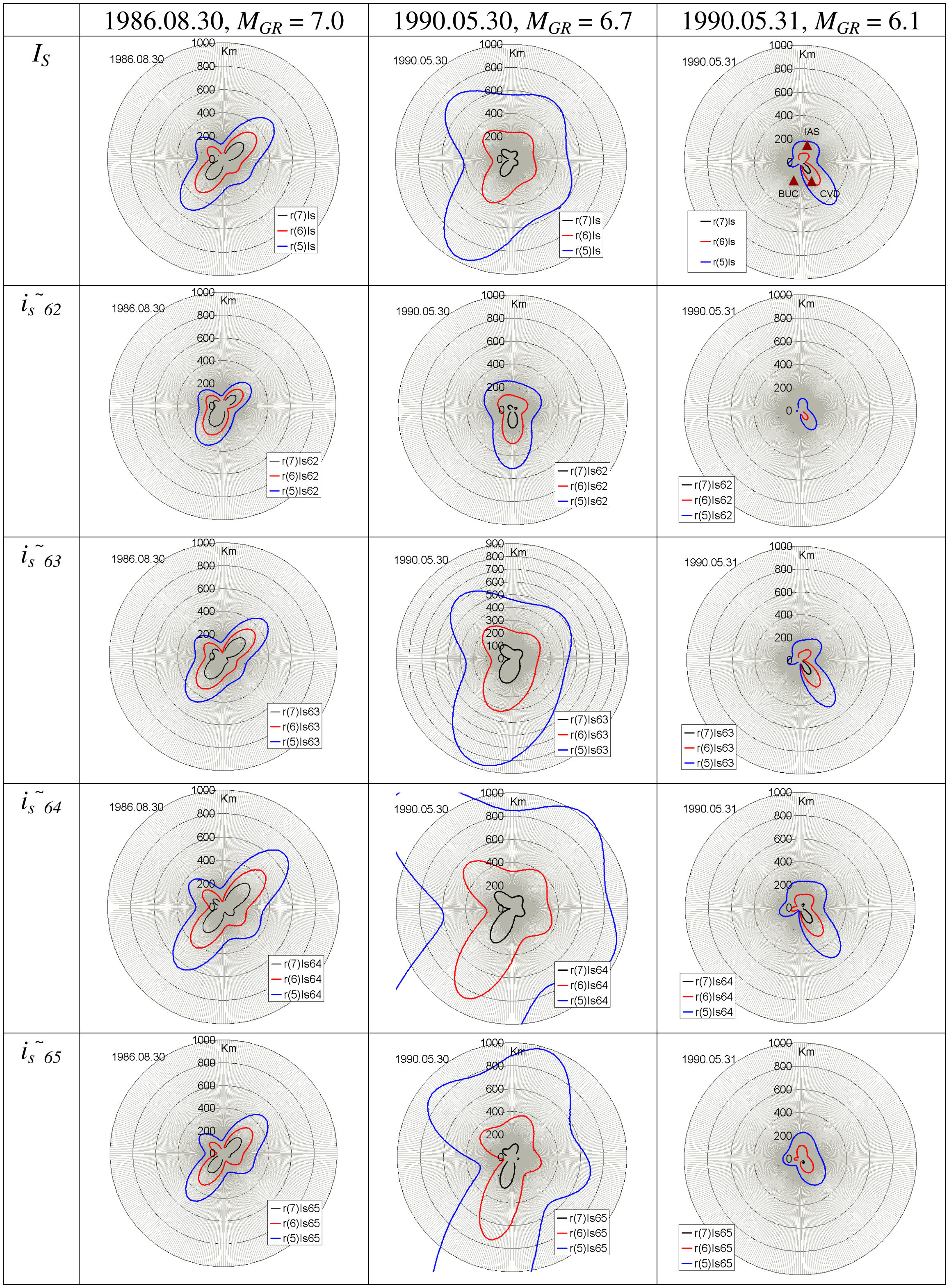


Fig. 8b. Directionality of attenuation, for various events and frequency bands
(common scale, up to epicentral distance of 1000 km)

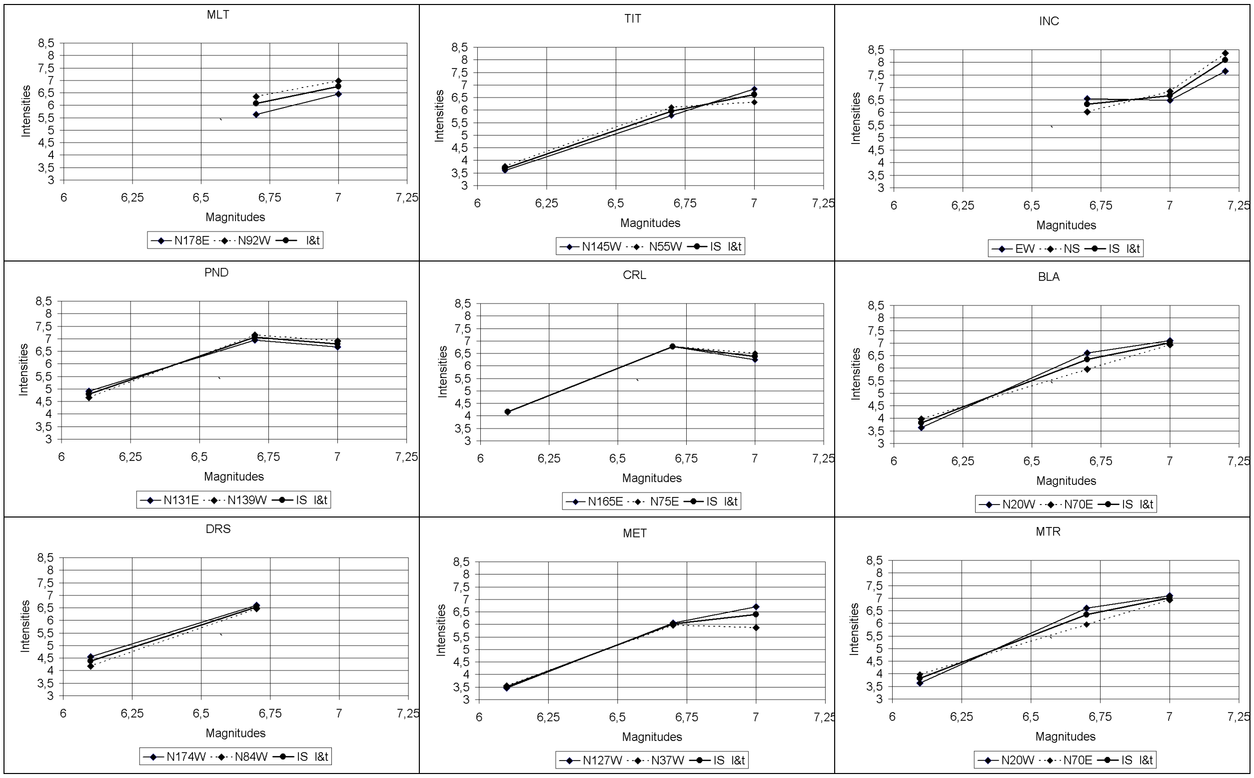


Fig. 9. Relationship between magnitudes and intensities I_S for various events and stations of Bucharest (see Fig. 4)

In order to provide more specific information, the relationship between I_S and earthquake magnitude is presented in Fig. 9 for stations of Bucharest, [8], (see map of Fig. 4) and in Fig. 10 for stations of province towns (see maps of Fig.'s 3 and 2a).

The *numerical results* on the features of attenuation are summarized in two tables:

- expressions of linear regression functions, as related to various frequency bands, as well as Fourier coefficients of the azimuthal directionality of radiation, in Table 3;
- r.m.s. values for various ground motion parameters, as related to regression functions and to the synthesis of the azimuthal Fourier expansion, respectively, in Table 4.

The results obtained lastly make it possible to come up with following remarks:

- the methodology developed led to a more complete insight into the features of attenuation, going up to the analysis in directional and spectral terms;
- the results of [10] were generally confirmed, but corrections had to be brought to the dominant azimuthal angles;
- out of the frequency bands considered, the band (2.0 Hz, 4.0 Hz) appeared to correspond to the highest intensities; this was followed by the bands (4.0 Hz, 8.0 Hz) and (1.0 Hz, 2.0 Hz), while the lowest frequency band, (0.5 Hz, 1.0 Hz), corresponded to the lowest intensities;
- differences between the dominant azimuthal angles for different frequency bands could be observed, especially for the event of 1990,05.30;
- the peculiarities of the 1990 events, which do not follow the "standard" radiation pattern are confirmed and raise problems concerning the features of the seismogenic zone activity;

It may be stated that the results obtained should be considered for the improvement of seismic zonation of the Romanian territory.

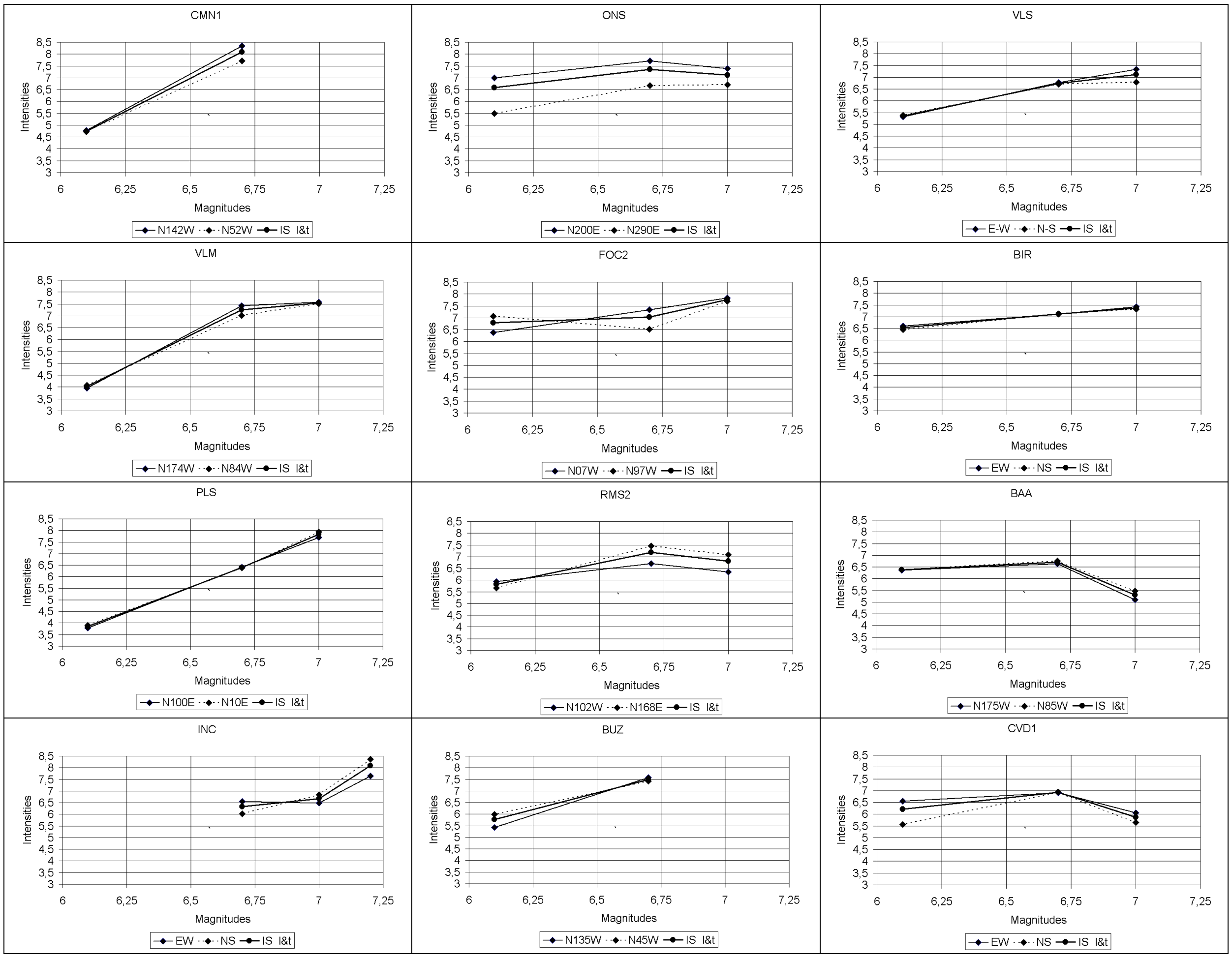


Fig. 10. Relationship between magnitudes and intensities I_S for various events and stations, mostly outside of Bucharest (see Fig. 4)

TABLE 3
RESULTS OF REGRESSION ANALYSIS IN SPECTRAL AND DIRECTIONAL TERMS

Event	Regression functions $I_0^{\sim}$ - $b\ \rho$, *for*					Fourier coefficients a_1, b_1 / a_2, b_2, for					Dominant radiation azimuth for I_S
	I_S	$i_s^{\sim}{}_{62}$	$i_s^{\sim}{}_{63}$	$i_s^{\sim}{}_{64}$	$i_s^{\sim}{}_{65}$	I_S	$i_s^{\sim}{}_{62}$	$i_s^{\sim}{}_{63}$	$i_s^{\sim}{}_{64}$	$i_s^{\sim}{}_{65}$	
1986. 08.30	7.352-6.019 ρ	7.437-8.870 ρ	7.840-7.691 ρ	7.669-5.769 ρ	7.179-6.218 ρ	-0.316, 0.150/ -0.275, 0.743	-0.564, -0.361/ -0.080, 0.869	-0.345, -0.028/ -0.229, 0.908	-0.274, 0.278/ -0.199, 0.717	-0.246, 0.292/ -0.240, 0.753	*N 53 °E*
1990. 05.30	7.312-2.800 ρ	7.179-4.398 ρ	7.560-3.323 ρ	7.580-2.463 ρ	7.228-2.457 ρ	-0.084, -0.062/ 0.192, 0.048	-0.256, -0.042/ 0.398, -0.016	-0.193, -0.064/ 0.291, 0.034	-0.093, -0.111/ 0.169, 0.112	-0.044, 0.038/ 0.430, 0.041	*N 209 ° E*
1990. 05.31	6,.86-3,.32 ρ	5.342-4.607 ρ	6.180-4.386 ρ	6.682-4.357 ρ	6.429-4.468 ρ	0.170, 0.772/ 0.042, -0.540	0.081, 0.739/ 0.069, -0.439	0.175, 0.859/ 0.086, -0.561	0.149, 0.710/ -0.029, -0.471	0.143, 0.460/ 0.068, -0.300	*N 143 ° E*

TABLE 4
R.M.S. VALUES OF GROUND MOTION PARAMETERS
(WITH RESPECT TO REGRESSION LINES / WITH RESPECT TO FOURIER SYNTHESIS)

Event	$\log_2$ *PGA*	$\log_2$ *PGV*	$\log_2$ *PGD*	$\log_2$ *EPAS*	$\log_2$ *EPVS*	I_S	$i_s^{\sim}{}_{62}$	$i_s^{\sim}{}_{63}$	$i_s^{\sim}{}_{64}$	$i_s^{\sim}{}_{65}$
1986. 08.30	0.910 0.648	0.975 0.752	0.965 0.809	0.892 0.613	0.956 0.755	0.871 0.631	1.124 0.936	1.022 0.763	0.900 0.617	0.926 0.657
1990. 05.30	0.680 0.656	0.670 0.630	0.847 0.814	0.698 0.667	0.603 0.571	0.579 0.561	0.700 0.676	0.729 0.706	0.679 0.665	0.730 0.684
1990. 05.31	0.761 0.843	0.801 0.909	0.931 1.004	0.842 0.953	0.914 1.073	0.844 0.986	0.864 0.920	1.037 1.165	0.846 0.975	0.659 0.680

6. FINAL CONSIDERATIONS

The developments presented in the paper are of two basic kinds: methodological and factual. The methodological developments refer to the ways of performing attenuation analysis, while the results obtained on this basis provide new information about the features of attenuation of the Vrancea seismogenic zone.

The main methodological developments that can be referred to concern:

- the measures of ground motion presented in subsection 3.1, used alternatively, with emphasis of the intensity measures I_S (global) and $i_s^{\sim}$ (φ', φ'') (frequency related, considered for various frequency bands (φ', φ''));
- the use of a generalization on Blake's attenuation law [2], as presented in subsection 3.2;
- the ways of performing statistical regression analysis, presented in subsections 3.3 and 3.4.

It may be stated that the use of the approaches presented made it possible to get a comprehensive insight into the features of attenuation for the Vrancea events referred to.

The remarks on attenuation presented at the end of section 4 were generally confirmed by the new step of work, summarized in section 5. One may present nevertheless some additional remarks in this view:

- the attenuation analysis was performed separately for the three events considered; in case one would have taken them together, the attenuation scatter would have increased considerably;
- the results presented add to the insight on the features of seismicity of Romania (due to Vrancea earthquakes) presented in [1], [3], [8], [9], [12];

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