Contributions above the Influence of the Strong Vrancea Earthquakes in Oltenia Region by Processing the Seismic Recording During Seismic Motions from 1986 and 1990

M. Calbureanu, R. Malciu, E. Albota, A. Ionescu and M. Lungu

***Abstract*—**This paper presents the analysis of the accelerographic records, the processing the data obtained by the seismic station from Craiova for the earthquakes of August 30, 1986, May 30 and May 31, 1990. Strong Vrancea earthquakes are analyzed in order to present conclusions regarding seismic zoning for Craiova and Oltenia region.

***Keywords*—**Oltenia seismicity, processing seismic records, Vrancea major seismic motions

I. Seismic Stations for Oltenia Region

SEISMIC stations placed on the Romanian territory that provided records used in analysis described during strong Vrancea earthquakes 1986 and 1990 are shown in Fig. 1.

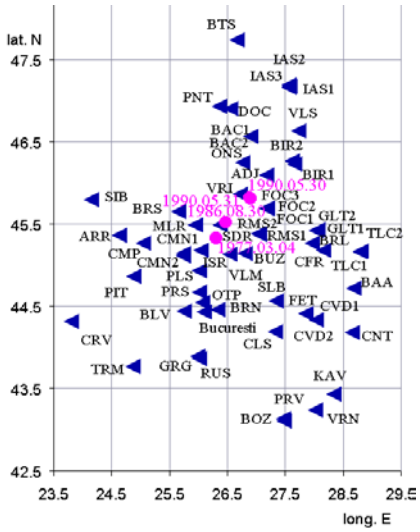

Fig.1 Seismic stations in the Romanian area that provided records during strong Vrancea earthquakes of 1977, 1986 and 1990

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It may be noticed the station from Craiova which provided recordings for both the two earthquakes of August 30, 1986 and the earthquakes of May 30 and May 31, 1990.

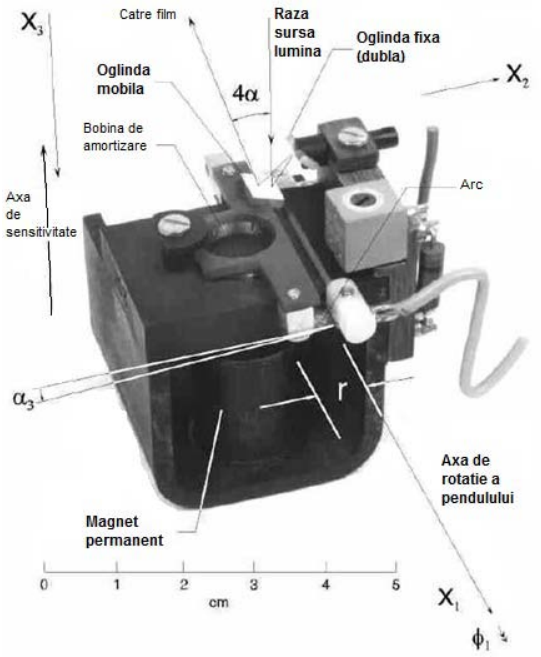
The seismic station 12 was located in the heart of Oltenia region, the centre of Craiova, in a building having a regime of height S + P + 7, made of reinforced concrete frames and masonry.

Fig. 2 Station of Craiova, IPJ building, 10, Titu Maiorescu Street

II. The Main Seismic Motion Vrancea Source Recordings

One of the most common types of analog accelerometer is the model SMA-1, manufactured by Kinemetrics Inc., USA, represented in Fig. 3.

(a)



(b)

Fig. 3 Analog accelerometer model SMA-1: (a) general view; (b) operating principle [1]

The accelerographs model SMA-1 used by INCERC network component stations provide records on photographic film. During recent strong earthquakes (magnitude greater than 6) 138 useful picture records were obtained, records which have been digitized and processed (2 records in 1977, 42 records in 1986 and 94 records in 1990).

The seismic stations of the INCERC National Seismic Network who provided useful records for strong Vrancea earthquakes from the second half of the twentieth century in the territory - including Oltenia Region - are shown in Fig. 4 (stations located in instrumented buildings).

The specialists concerns regarding the characterization of seismic motion consider two fundamentally different situations [2]:

- On the one hand, the case of previous movements, about which certain data is available (in the best case, instrumentation data of good quality);

- On the other hand, the case of possible movements (or expected) in the future, whose features have to be anticipated.

Fig. 4 INCERC seismic stations which provided records in seismic instrumented buildings during Vrancea earthquakes of 1977, 1986 and 1990 [4]

The current situation of the main seismic network in Romania is represented in Figure 5 [5].

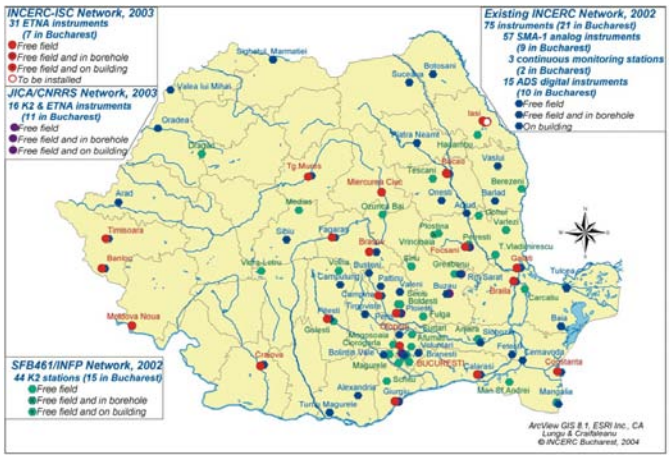


Fig. 5 Seismic networks including Craiova station, Romania (2003)

General information about seismic motions starting with the earthquake of the March 4th 1977 to the one of April 25th 2009 is presented in Table 1.

Table 1 General data about seismic motions

Earthquake	LatN	LongE	Earthquake Cod	h(km)	Data	Mw
Vrancea **M** (*G-R*) = **7.2**	45.34	26.30	19771	109	1977.03.04	7.5
Vrancea **M** (*G-R*) = **7.0**	45.53	26.47	19861	133	1986.08.30	7.3
Vrancea **M** (*G-R*) = **6.7**	45.82	26.90	19901	91	1990.05.30	7.0
Vrancea **M** (*G-R*) = **6.1**	45.83	26.89	19902	79	1990.05.31	6.4
Vrancea **M** (*G-R*) = **5.1**	45.49	26.27	19991	151	1999.04.28	5.3
Vrancea **M** (*G-R*) = **5.1**	45.76	26.59	20091	100	2009.04.25	5.3

Table 2, 3, 4 and 5 contain information about station address, geographic location and earthquakes records values for the earthquakes of August 30, 1986, May 30 and May 31, 1990.

Table 2 Information about the location of the seismic station from Craiova

Seismic station	Address	Station Cod	LatN	LongE	Regime of height	Seismic network
Craiova	CRAIOVA, 10, Ioan Maiorescu Street	CRV	44.321	23.798	P+7E	INCERC

Table 3a Values of maximum acceleration, velocity and displacement recorded on longitudinal direction for earthquakes of August 30, 1986, May 30 and May 31, 1990

Seismic station	Earthquake Cod	Orientation L	accmaxL	velmaxL	dismax L
CRAIOVA	19861	N05E	112.30	12.390	2.4920
CRAIOVA	19901	N05E	112.50	10.090	1.4400
CRAIOVA	19901	N95E	48.54	3.670	0.4795

Table 3b Values of maximum acceleration, velocity and displacement recorded on transversal direction for earthquakes of August 30, 1986, May 30 and May 31, 1990

Seismic station	Earthquake Cod	Orientation T	accmaxT	velmaxT	dismax T
CRAIOVA	19861	N95E	140.70	12.380	1.8670
CRAIOVA	19901	N95E	49.24	1.850	0.2227
CRAIOVA	19901	N05E	62.41	4.950	0.6371

Table 3c Values of maximum acceleration, velocity and displacement recorded on transversal direction for earthquakes of August 30, 1986, May 30 and May 31, 1990

Seismic station	Earthquake Cod	Orientation V	accmax V	velmax V	dismax V
CRAIOVA	19861	V	61.0300	2.3110	0.3898
CRAIOVA	19901	V	102.4000	7.9470	0.8816
CRAIOVA	19901	V	23.2600	1.4880	0.2708

To define the intensity of the ground motion at a point, considering the following characteristics of seismic ground motion are considered:

- Characteristics determined directly by examining the accelerograms and their integrals (peak ground acceleration, PGA, peak ground velocity, PGV, peak ground displacement, PGD);
- Characteristics determined using the averages maxima for 0.4 seconds length of action spectra values (effective peak acceleration, EPA, effective speed peak, EPV, effective displacement peak EPD);
- The corner periods (control periods) TC and TD;
- Global instrumental intensity (Arias intensity, IA, based on response spectrum intensity, Is);
- Instrumental intensity averaged over different spectral ranges (intensities based on response spectrum and intensities based on the spectrum of destructivity) [10].

Table 4a Values of peak ground acceleration (pga), peak ground velocity (pgv) and peak ground displacement (pgd) for earthquakes of August 30, 1986, May 30 and May 31, 1990

Seismic Station	Earthquake Cod	Axis Cod	Axis no.	pga	pgv	pgd
Craiova	19861	N05E	1	1.1230	0.1239	0.0249
Craiova	19861	N95E	2	1.4070	0.1238	0.0187
Craiova	19861	V	3	0.6103	0.0231	0.0039
Craiova	19901	N95E	1	0.4854	0.0367	0.0048
Craiova	19901	N05E	2	0.6241	0.0495	0.0064
Craiova	19901	V	3	0.2326	0.0149	0.0027

Table 4b Values of effective peak acceleration (epa), effective peak velocity (epv) and effective peak displacement (epd) for earthquakes of August 30, 1986, May 30 and May 31, 1990

Seismic Station	Earthquake Cod	Axis Cod	Axis no.	epa	epv	epd
Craiova	19861	N05E	1	1.8683	0.2323	0.0305
Craiova	19861	N95E	2	1.2746	0.1666	0.0254
Craiova	19861	V	3	0.0000	0.0000	0.0000
Craiova	19901	N95E	1	0.5230	0.0342	0.0084
Craiova	19901	N05E	2	0.7317	0.0496	0.0087
Craiova	19901	V	3	0.0000	0.0000	0.0000

Table 5 Values of control periods (corner periods) Tc and Td for earthquakes of August 30, 1986, May 30 and May 31, 1990

Seismic Station	Earthquake Cod	Axis Cod	Axis no.	Tc	Td
Craiova	19861	N05E	1	0.78	0.83
Craiova	19861	N95E	2	0.82	0.96
Craiova	19861	V	3	0.00	0.00
Craiova	19901	N95E	1	0.41	1.55
Craiova	19901	N05E	2	0.43	1.10
Craiova	19901	V	3	0.00	0.00

III. Intensity Values Based on the REsponse and Destructiveness Spectra for Earthquakes of August 30, 1986, May 30 and May 31, 1990

The tables below present the intensity values based on response spectra for Vrancea seismic motions of August 30, 1986, May 30 and May 31, 1990.

Table 6 Intensity values based on response spectra for Vrancea seismic motions of August 30, 1986, May 30 and May 31, 1990

Earthquake Cod	Axis Cod	Axis no.	Is	Is1	Is31	Is32	Is33
19861	N05E	1	7.92	7.54	6.86	7.98	6.95
19861	N95E	2	7.77	7.45	6.95	7.83	7.11
19861	V	3	7.85	7.50	6.91	7.91	7.04
19901	N95E	1	6.67	6.30	4.93	6.66	6.22
19901	N05E	2	6.86	6.58	5.45	6.98	6.39
19901	V	3	6.78	6.46	5.26	6.85	6.31

Earthquake Cod	Axis Cod	Axis no.	Is61	Is62	Is63	Is64	Is65	Is66
19861	N05E	1	6.11	7.15	8.22	7.50	7.02	6.85
19861	N95E	2	5.85	7.26	7.78	7.87	7.20	7.01
19861	V	3	6.00	7.21	8.05	7.72	7.12	6.94
19901	N95E	1	4.82	5.03	6.26	6.89	6.28	6.15
19901	N05E	2	4.92	5.70	6.68	7.17	6.49	6.26
19901	V	3	4.87	5.47	6.51	7.05	6.40	6.21

Earthquake Cod	Axis Cod	Axis no.	Is121	Is122	Is123	Is124	Is125
19861	N05E	1	5.36	6.40	7.09	7.20	8.36
19861	N95E	2	4.96	6.15	6.89	7.47	7.93
19861	V	3	5.20	6.29	7.00	7.36	8.19
19901	N95E	1	4.72	4.90	4.91	5.12	5.85
19901	N05E	2	4.74	5.05	5.26	5.93	6.19
19901	V	3	4.73	4.98	5.12	5.68	6.05

Earthquake Cod	Axis Cod	Axis no.	Is126	Is127	Is128	Is129	Is 1210	Is 1211	Is 1212
19861	N05E	1	8.02	7.53	7.47	7.10	6.94	6.87	6.84
19861	N95E	2	7.56	7.63	8.03	7.25	7.14	7.04	6.97
19861	V	3	7.84	7.58	7.83	7.18	7.05	6.96	6.91
19901	N95E	1	6.48	6.61	7.06	6.39	6.15	6.22	6.08
19901	N05E	2	6.92	6.99	7.30	6.61	6.33	6.25	6.26
19901	V	3	6.75	6.84	7.19	6.51	6.25	6.24	6.18

Table 7 Intensity values based on destructiveness spectra for Vrancea seismic motions of August 30, 1986, May 30 and May 31, 1990

Earthquake Cod	Axis Cod	Axis no.	Ia	Id1	Id31	Id32	Id33
19861	N05E	1	7.82	7.85	7.15	8.30	7.25
19861	N95E	2	7.58	7.62	7.14	8.02	7.14
19861	V	3	2.50	7.75	7.15	8.18	7.20
19901	N95E	1	6.33	6.34	4.76	6.73	6.19
19901	N05E	2	6.54	6.55	5.20	6.94	6.37
19901	V	3	2.50	6.45	5.03	6.85	6.29

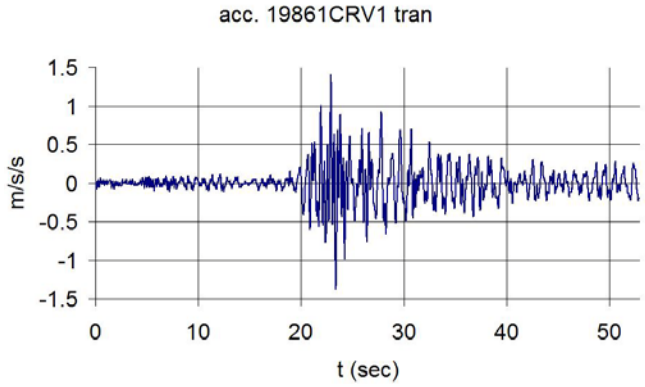
Earthquake Cod	Axis Cod	Axis no.	Id61	Id62	Id63	Id64	Id65	Id66
19861	N05E	1	6.10	7.46	8.56	7.69	7.33	7.16
19861	N95E	2	5.82	7.47	8.04	8.00	7.26	6.98
19861	V	3	5.98	7.47	8.37	7.87	7.30	7.08
19901	N95E	1	4.58	4.90	6.18	6.98	6.33	6.01
19901	N05E	2	4.64	5.46	6.35	7.21	6.55	6.08
19901	V	3	4.61	5.25	6.28	7.11	6.45	6.05

Earthquake Cod	Axis Cod	Axis no.	Id121	Id122	Id123	Id124	Id125
19861	N05E	1	5.25	6.39	7.20	7.64	8.75
19861	N95E	2	4.93	6.12	7.02	7.70	8.24
19861	V	3	5.11	6.28	7.12	7.67	8.56
19901	N95E	1	4.49	4.67	4.62	5.07	5.77
19901	N05E	2	4.55	4.72	5.15	5.65	5.91
19901	V	3	4.52	4.69	4.95	5.44	5.85

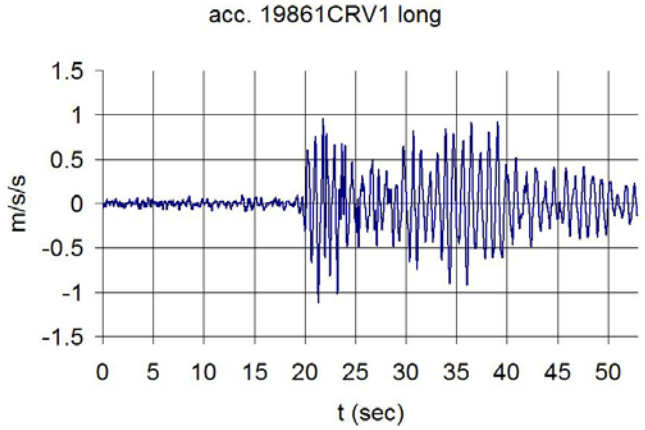
Earthquake Cod	Axis Cod	Axis no.	Id126	Id127	Id128	Id129	Id 1210	Id 1211	Id 1212
19861	N05E	1	8.25	7.71	7.68	7.41	7.23	7.17	7.15
19861	N95E	2	7.70	7.69	8.19	7.37	7.13	7.00	6.96
19861	V	3	8.05	7.70	8.00	7.39	7.18	7.09	7.06
19901	N95E	1	6.40	6.61	7.19	6.47	6.13	6.09	5.92
19901	N05E	2	6.58	7.00	7.35	6.69	6.34	6.14	6.02
19901	V	3	6.50	6.84	7.28	6.59	6.25	6.11	5.97

In the next paragraph the time variation of acceleration, velocity and displacement for the two recordings are presented as an example of processing: Craiova earthquake of August 30, 1986, May 30 and May 31, 1990. The spectral points achievement corresponding to each of the two horizontal components of recorded accelerograms may be noticed.

The absolute accelerations, relative velocities and relative displacements (horizontal components) response spectra are represented and the "effective" values of maximum acceleration, maximum speed and maximum displacement are also shown. The relative velocities and accelerations response spectra are represented in normal and double logarithmic coordinates, highlighting the levels for Sa, Sv and Sd and the control periods (corner periods) Tc and Td [2].

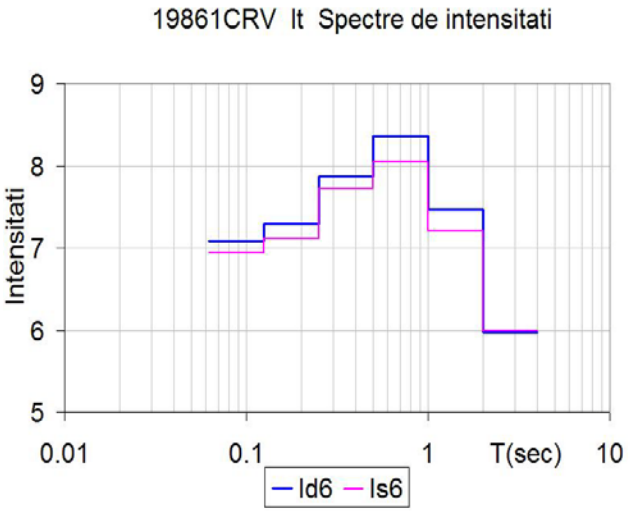


(a)

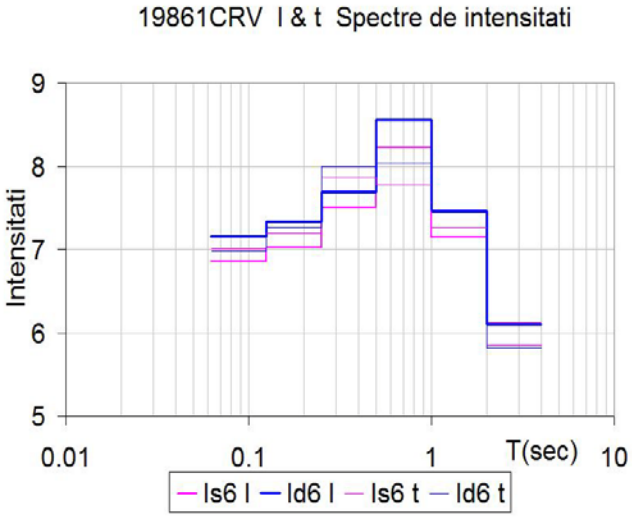


(b)

Fig. 6 Accelerograms for the earthquake of 1986, recorded in Craiova; (a) on the transverse direction; (b) on the longitudinal direction



(a)



(b)

Fig. 7 (a), (b) The absolute accelerations and intensities response spectra for recorded Craiova earthquake of 1986

Instrumental data were mainly obtained using analog accelerographs model SMA-1. The primary seismic information was digitized and standard processed (correction and filtering) in order to give useful results for direct engineering:

- Numerical records as time variation functions (accelerograms, velocitygrams, seismograms of displacements);
- Seismic response spectra for absolute acceleration, relative speed, pseudo relative velocity, relative displacements etc.).
- complex Fourier spectra, amplitude Fourier spectra etc., results from numerical Fourier transformation [6].

In Table 8 there are presented the results of the records processing from Craiova - Centre (s) (CRV1) obtained during Vrancea earthquake of August 30, 1986, (861).

Table 8 Records processing from Craiova - Centre (s) (CRV1) obtained during Vrancea earthquake of August 30, 1986, (861)

Station	Code Axis	pga	pgv	pgd	epa	epv	epd	T_C	T_D	I_S
Craiova	N95E	1.123	0.124	0.025	1.867	0.232	0.030	0.78	0.83	7.88
Craiova	N05E	1.407	0.124	0.017	1.275	0.167	0.025	0.82	0.96	7.67
Craiova	V	0.610	0.023	0.004						

Global Intensities

A. The global intensity based on response spectra, Is

It is given by the expression:

$$Is = \log_4 (EPAM \times EPVM) + 8.0 \quad (1)$$

where:

$$EPAM\ [m/s^2] = \max_T s_{aa}(T, 0.05) / 2.5; \quad (2)$$

$$EPVM\ (m/s) = \max_T s_{va}(T, 0.05) / 2.5 \quad (3)$$

- $s_{aa}(T, n)$ is the response spectrum of absolute accelerations related to periods, $[m/s^2]$;
- $s_{va}(T, n)$ is the response spectrum of absolute velocities related to periods [m/s].

B. The Arias intensity, I_A

It is given by the expression:

$$I_A = \log_4 Q_A + 6.75 \quad (4)$$

where:

$$Q_A = \int w_g^2(t)dt \quad (5)$$

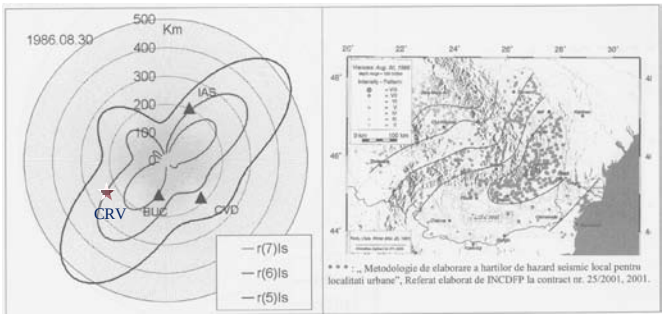


Fig. 8 Global intensities based on the spectrum (left) and macroseismic intensities (right) corresponding to the Vrancea earthquake of August 30, 1986

In Fig. 9 and Fig. 10 there are represented the rosettes of radiation and the regression lines as a result of the peak ground acceleration, pga $[m/s^2]$, and peak ground velocity, pgv [m/s], analysis for the strong seismic movement recorded on our country territory on August 30, 1986.

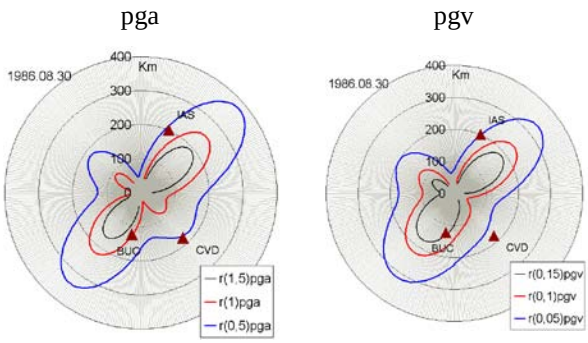


Fig. 9 Radiation rosettes presented for different values of the peak ground acceleration, pga (m/s^2), and peak ground velocity, pgv (m/s)

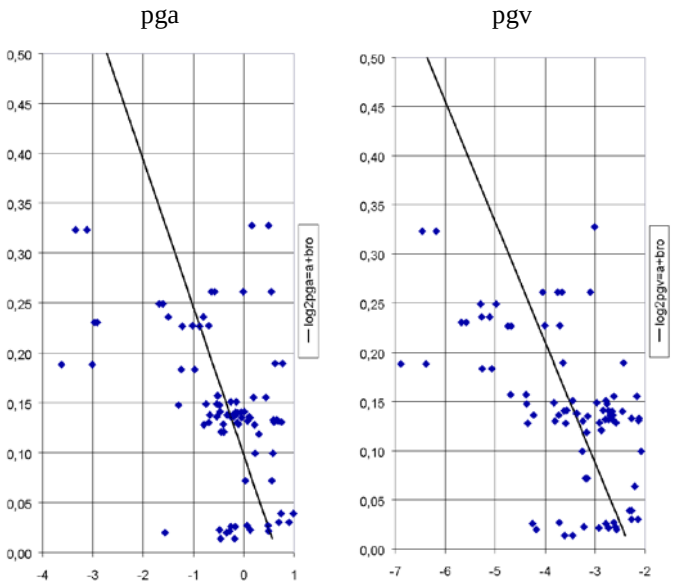


Fig. 10 regression lines presented for the peak ground acceleration pga (m/s^2), and peak ground velocity, pgv (m/s)

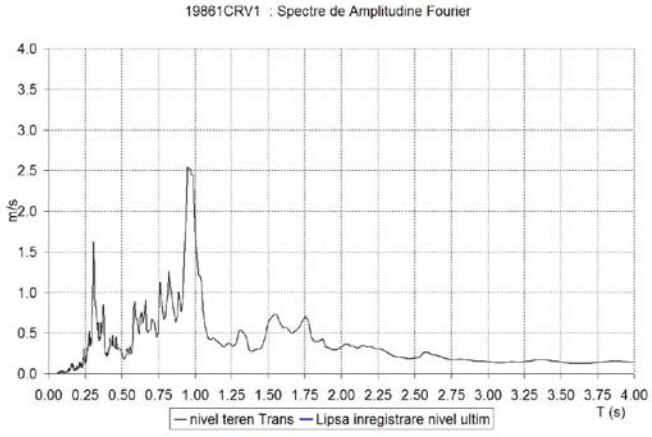


Fig. 11 Fourier amplitude spectra in absolute accelerations corresponding to the Vrancea earthquake of August 30, 1986

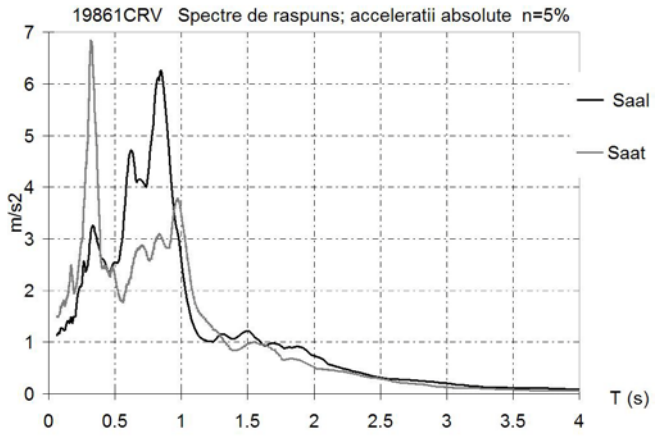


Fig. 12 Relative response spectra in relative velocities corresponding to the Vrancea earthquake of August 30, 1986

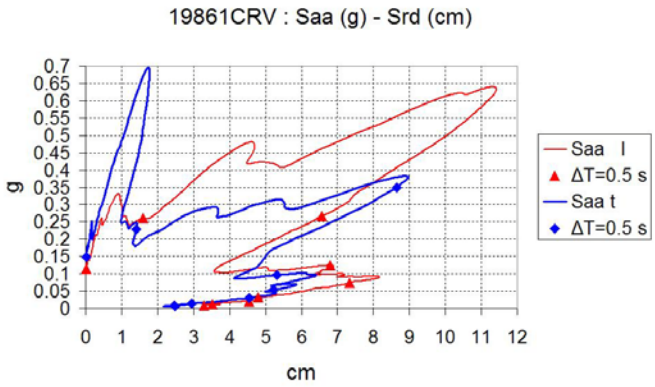


Fig. 13 Response spectra Saa (g) on the longitudinal and transverse directions for 0.5 s time range corresponding to the Vrancea earthquake of August 30, 1986

IV. Conclusions Regarding the Studies of Oltenia Region Seismic Zoning

Romania is characterized [1] by high seismicity, comparable to that of Greece and Italy, in the whole seismotectonic assembly of Europe. Although less intense, the seismicity of Romania zone is comparable to that of Turkey and other countries with the highest seismicity (Japan, China, U.S. - California etc.), especially by producing major earthquakes which frequently affect densely populated areas, with social and economic activity, having a decisive share in the national activity. According to the opinion of C.F. Richter, expressed in a letter addressed to the chairman of the National Council for Science and Technology after the earthquake of March 4th, 1977, Bucharest is the most endangered capital in the world in terms of seismic risk, particularly because of the frequency with which it is subjected to major earthquakes effects.

The complexity and variety of the Romanian territory tectonics and especially of Vrancea Zone, which is centered on the triple junction of three tectonic units, the East European

Plate, the Intra-Alpine sub-plate and Moesic sub-plate determines the generation of intra-crustal and sub-crustal earthquakes in the curvature of the Eastern Carpathian (Vrancea) called *"Vrancea seismogenic zone"*.

The complexity and dynamics of crustal and sub-crustal tectonic structures from this area determine the earthquakes occurrence within the earth's crust (earthquakes intra-crustal with depths of less than 60-70 km) and under the crust (sub-crustal earthquakes with depths over 70 km)[3].

Vrancea seismogenic zone may be characterized by the following features:

- epicentral area of approximately 2100 km^2;
- existence of certain regularities in earthquakes generation;
- persistence of earthquake foci in about the same place, on a global scale;
- high rate of seismicity (2-3 destructive earthquakes per century);
- usual appearance of main shock as doublets;
- large areas supporting significant macroseismic effects associated with these earthquakes, which sometimes go beyond the country's borders;
- hypocenters of major subcrustal earthquakes between 60-200 km;
- seismogenesis processes as well as tectonic, structural and geological features, which usually cause the strong elongated form of izoseist map on NE-SW direction and the emergence of local amplification of seismic intensity at distances of 200-300 km from the epicenter, macroseismic effects manifested sometimes at long distances (Warsaw, St. Petersburg, Moscow, Istanbul, Sofia, Belgrade, Budapest and so on) [10];
- about 50% of the country strongly affected by the strongest Vrancea earthquakes[7], [8].

The characterization of seismic ground motion during strong Vrancea earthquakes is based on instrumental data obtained by accelerographic networks in our country (most of accelerographs are SMA-1 type, manufactured by Kinemetrics in Pasadena, California). The principal mean of seismic ground motion characterization was the determination of (linear) response spectra for absolute seismic accelerations [4].

To ensure the availability of complete data and conclusive response spectra on the horizontal direction were determined not only on the registration directions, but for a total of 12 azimuthal equidistant horizontal directions (azimuthal equidistance: 15 □a according to a methodology established by the author and presented for the first time in [6].

The results examination allows the formulation of the following conclusions:

- the argument *p*, introduced by Blake's law is suitable because the regression line crosses with a good symmetry the representative points cloud for local situations, from various stations in the country;
- attenuation is more rapid for the event of August 30, 1986, than for the event of May 30, 1990, although declared focal depth was higher for the first event;
- statistical spread is more pronounced for the event of August 30, 1986, than for the event of May 30, 1990;
- intensity type parameters are applicable because their results spread tend to be lower than the base-2 logarithms of parameters with kinematic significance;
- while the radiation directivity was approximately on NE-SW direction for the event of August 30, 1986, she was roughly on NS direction for the event of May 30, 1990;
- radiation directivity was different at the same event for different spectral bands;
- the more marked radiation tendency towards south of the event of May 30, 1990, is consistent with some findings of macroseismic survey in north-eastern Bulgaria, whereby the effects of this event would have been more severe than the ones of the event of March 4, 1977.

V. Conclusions for Zoning Studies of Craiova

Based on response spectra determined for events of August 30, 1986, and May 30, 1990, the response spectra for CRV1 station from Craiova were achieved as represented in Fig. 3 and 4, in a rough sort of map. Examination of the spectra shows:

* the presence of main spectral peaks at short period of time (about 0.5 s for the event of August 30, 1986, and approx. 0.3 s for the event of May 30, 1990)
* the presence of a secondary spectral peak at long period of time (about 1.5 s for the event of August 30, 1986);
* significant differences between spectral ordinates of the curves corresponding to different azimuthal directions.

Examination of instrumental intensities discrete spectra highlights the followings:

* differences of configuration that are homologous to those determined by the response spectra;
* a common trend of displacement towards shorter periods of maximum spectral ordinates when passing from the first to the second event.

The belief of specialists that Vrancea earthquakes cause relatively long period accelerographic records in many areas, mainly due to local conditions, changed especially because of the macroseismic tests and instrumental data obtained during strong Vrancea earthquake of 1990.

Examination of Fig. 3 and Fig 4 allows us to deduce the followings:

- the spectral peak located near the period of 1.5 seconds was present (as second peak) in all spectra, during the August 30, 1986 earthquake;
- this spectral peak has disappeared in all spectra during the May 30, 1990 earthquake;
- it may be concluded that the spectral peak located near the period of 1.5s, which was dominant during the earthquake of March 4, 1977, according to INCERC registration, was dominant at that time on a large area covering the region of Oltenia;
- during the earthquakes of August 30, 1986 and May 30, 1990, there were main spectral peaks at shorter periods, but

these occurred randomly from one event to another and from one station to another;

- in agreement with the findings above, the decisive contribution of the focal mechanism and propagation path on the spectral composition of seismic ground motion is obvious, due to the enrollment of the mentioned [5]

The examination of Fig. 3 and Fig 4 may determine the following conclusions:

- spectral peak of approx. 1.5 s noticed for the March 04, 1977 and the August 30, 1986 earthquakes, but absent for the May 30, 1990 earthquake came from the source and was not determined by local conditions;

- this spectral peak had had to be present as main spectral peak with close ordinates from one station to another, in all stations during the March 04, 1977 earthquake;

- spectral peaks of short periods varied from one event to another and this fact was probably determined by the seismic radiation particularities and not by the local conditions [13].

Results regarding the effect of local geological conditions, obtained in different ways, are converging. Prevalence of focal mechanism influence on local geological conditions occurs for several sites, including those of Craiova (although ground conditions are the same): significant differences between spectral ordinates for different azimuthal directions, significant differences between spectral peaks from an earthquake to another. In Craiova, superficial geological packages didn't behave as powerful dynamic filters [9].

For future strong earthquakes spectral peaks of long periods are expected, which may differ from what was found for the earthquake of March 4, 1977, (the spectral peak registered for the EW component of INCERC accelerograms during the earthquake of March 4, 1977, may be around 2.25 sec.). The data of instrumental origin and its processing does not support a seismic microzoning of Craiova[12].

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