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INFLUENCE OF SOURCE MECHANISM VERSUS THAT OF LOCAL CONDITIONS UPON SPECTRAL CONTENT OF GROUND MOTION

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SUMMARY

The instrumental data obtained during the strong 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) provided rich accelerographic information, which put to evidence the features of spectral content of ground motion for numerous stations. Locations with tendency of stability of spectral characteristics, as well as locations with tendency to strong variability of the same from one event to another were put to evidence. The paper is intended to contribute to an explanation of the reasons of these differences, emphasizing the contributions of source mechanism and of local conditions respectively for specific cases. Data and tools used in this view are represented by sequences of response spectra, records of ambient oscillations with running Fourier spectra and transfer functions (scalar and vectorial) of relevant geological packages. Reconciliation of results and recommendations are finally presented.

1. INTRODUCTION

Romania is frequently subjected to strong earthquakes. The most important seismogenic zone affecting an important part of the territory of Romania (as well as parts of the territories of neighbouring countries) is the Vrancea seismogenic zone (*VSZ*). During the 20th century three major Vrancea earthquakes of Gutenberg-Richter magnitudes not less than 7.0 occurred: on 1940.11.10 (M_{GR} = 7.4), 1977.03.04 (M_{GR} = 7.2) and 1986.08.30 (M_{GR} = 7.0). Instrumental strong motion information became available starting with the 1977 event, but rich instrumental information was first obtained during the event of 1986 and then during the subsequent events of 1990.05.30 (M_{GR} = 6.7) and 1990.05.31 (M_{GR} = 6.1). This was due to the post-1977 development of the strong motion network, first of all thanks to the generous support provided by US-AID. The fact that more than 150 valuable SM records (most of them at ground level, but some of them at the upper floors of high rise buildings) made Romania a country with rather rich instrumental

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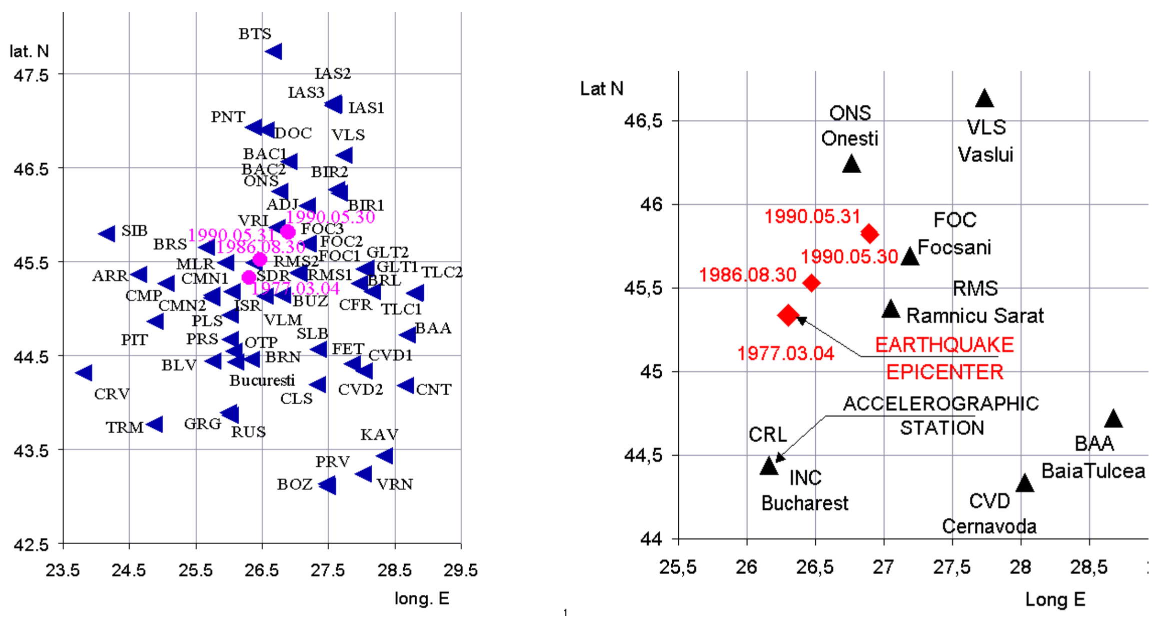
information. This information is important because it refers to the activity of a frequently acting source zone and makes it possible to put to evidence some relevant features that may be more or less stable or variable from one event to the other. The paper is devoted essentially to the spectral characteristics of ground motion due to Vrancea earthquakes. Alternative data and tools are used in this connection: sequences of response spectra, records of ambient ground motion and running Fourier spectra derived on this basis, scalar and vectorial transfer functions characterizing upper geological packages. Reconciliation of results is looked for and some conclusions and recommendations are finally presented.

2. DATABASE USED

The basic data used in view of analyzing the influence of source mechanism and of local conditions consisted of:

- the accelerograms having become available subsequently to the earthquakes referred to;
- records of microtremors at selected sites (in the neighbourhood of some recording stations);
- data on the geological columns and estimates on the *S* wave propagation velocities for the various layers considered.

The geographic distribution of accelerographic strong motion stations considered (which cover the eastern part of Romania) is presented in Fig. 1, as follows: in Fig. 1a, accelerographic stations; in Fig. 1b, some stations to which some explicit reference is made in the paper. A detailing of the network for the City of Bucharest is presented in Fig. 2.



a) Network of eastern part of Romania and of North - eastern part of Bulgaria

b) Epicentres and stations referred to in the paper

Fig.1. Accelerographic network

The geographic coordinates for some selected stations referred to in the paper are given in Table 1.

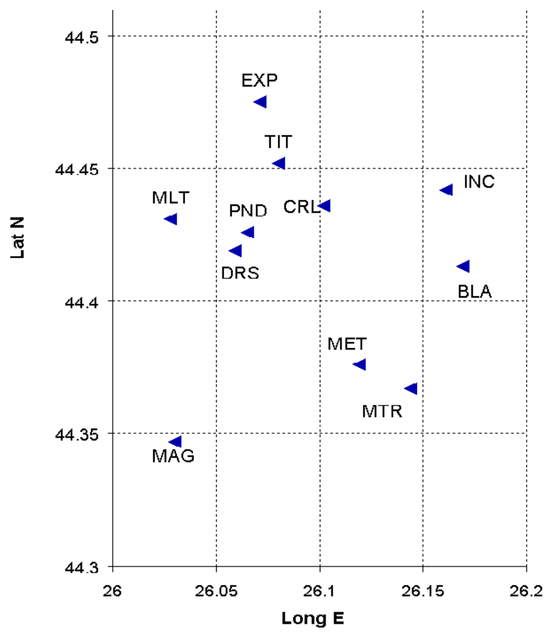


Fig. 2. Accelerographic network of the City of Bucharest

TABLE 1
GEOGRAPHIC COORDINATES OF ACCELEROGRAPHIC STATIONS REFERRED TO

No. crt.	Accelerographic station	Lat. North	Long. East	Symbol	1986. 08.30	1990. 05.30	1990. 05.31
1	Baia-Tulcea	44.63	28.68	BAA	*	*	*
2	Bucharest-Balta Albă (s)	44.41	26.17	BLA	*	*	*
3	Bucharest-Carlton (s)	44.44	26.10	CRL	*	*	*
4	Cernavodă-Centre	44.33	28.03	CVD1	*	*	*
5	Bucharest-Drumul Sării	44.42	26.06	DRS		*	*
6	Bucharest-EREN	44.47	26.07	EXP	*		
7	Focşani –Hotel	45.70	27.20	FOC1	*		
8	Focşani-Centre	45.43	27.05	FOC2	*	*	*
9	Bucharest-INCERC	44.44	26.16	INC	*	*	
10	Bucharest-Met. Berceni	44.38	26.12	MET	*	*	*
11	Bucharest-Militari	44.43	26.03	MLT	*	*	
12	Bucharest-Metro IMGB	44.37	26.14	MTR	*	*	*
13	Oneşti-Centre	46.68	26.75	ONS	*	*	*
14	Bucharest-Panduri	44.43	26.07	PND	*	*	*
15	Râmnicul Sărat (Town Hall)	45.37	27.33	RMS1	*	*	
16	Râmnicul Sărat (School)	45.38	27.05	RMS2	*	*	*
17	Bucharest-Titulescu	44.45	26.07	TIT	*	*	*
18	Vaslui	46.65	27.73	VLS	*	*	*

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

3. METHODOLOGICAL ASPECTS

3.1. Determination of 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 [7]. This was done for 5% critical damping. The availability of response spectra along 12 equidistant direction made it possible to emphasize the differences appearing for different directions of ground motion.

Attention was paid not only to the features of individual motions or spectra, but also to sequences of spectra, which make it possible to put to evidence tendencies to stability or to variability (from one event to another) of the features of ground motion.

Corner periods of response spectra (for 5% critical damping) were determined too. The velocity / acceleration corner period T_C was determined according to expression

$$T_C = \max_T [S_{aa} (T, 0.05) \times T\,] \,/\, \max_T [S_{aa} (T, 0.05)] \qquad (1)$$

while the displacement / velocity corner period T_D was determined according to expression

$$T_D = \max_T [S_{aa} (T, 0.05) \times T^2] \,/\, \max_T [S_{aa} (T, 0.05) \times T] \qquad (2)$$

In cases when the motion along two orthogonal horizontal directions had to be simultaneously considered, the expression (1) was adapted as

$$T_C = \max_T \{[S_{aax}^{\;2} (T, 0.05) + S_{aay}^{\;2} (T, 0.05)]^{1/2} \times T\,\} \,/\, \max_T \{[S_{aax}^{\;2} (T, 0.05)] + S_{aay}^{\;2} (T, 0.05)]^{1/2}\} \qquad (1')$$

A similar generalization was adopted for T_D.

3.2. Dependence of corner periods on magnitudes

The dependence of corner periods on magnitudes was considered separately for individual stations, paying attention to the variation of corner periods from one event to the other. The variation referred to was plotted in figures concerning several stations, in order to make easy a comparison between different stations.

3.3. Recording and processing of ambient oscillations

Ambient ground oscillations were recorded by means of a Kinemetrics data acquisition system at several sites. The length of records was in the range of tens of minutes. The sampling rate was of 200 SPS.

The processing was organized such, as to determine running Fourier spectra for some relevant segments of the records. The time window length chosen used for processing of records was equivalent to 20 s.

3.4. Transfer functions of superficial geological packages

The dynamic model adopted for a superficial geological package was defined as follows:

- plane-parallel stratification;
- homogeneous layers, with jumps of properties at interfaces between adjacent layers;
- isotropic material, with physically linear behaviour; damping characteristic independent of oscillation frequency (results presented correspond to 5% critical damping);
- direction of wave propagation: vertical (normal to layer interfaces) and consideration of plane *S* waves (unique oscillation direction: horizontal);

- numbering of layers: downwards;
- imposing conditions of continuity of displacements and stresses at interfaces of adjacent layers.

Sinusoidal oscillations were basically considered, in order to determine (complex, scalar) transfer functions, defined as ratios of complex amplitudes at free surface to complex amplitudes of motion at lower boundary of a geological package.

Besides that, spatial transfer functions, which are functions not only of the circular frequency, but also of the abscissa measured along the propagation direction, were determined too, in order to get a picture of the deformation of the geological package as a whole.

4. CHARACTERISTICS OF SEQUENCES OF RESPONSE SPECTRA

Sequences of response spectra are presented for some relevant stations in Fig.'s 3 and 4. They refer to the strong earthquakes referred to, 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). This information is completed by means of the plots of Fig.'s 5 and 6, which put to evidence the dependence of corner periods T_C (solid lines) and T_D (dotted lines) on magnitude (some data concern also the moderate earthquake of 1999.04.28 of M_{GR} = 4.8).

A first basic remark: a look at the features of strong motion records at hand and of response spectra determined on this basis showed that it is particularly important to consider the whole of data at hand. It turned out that the isolated consideration of one station or even of one event as a whole (for the whole network) could lead to non-realistic, distorted, conclusions. This is why the availability of strong motion data for several events originating in the same source zone is so important. This approach made it possible to derive results and conclusions from various viewpoints. The main results obtained to date show that:

- for each of the events, taken separately, there were quite strong similarities for the time histories of displacements and even of velocities of ground motion at several recording stations, located along an approximately 100 km long alignment oriented N-S and along an approximately 50 km long alignment oriented E-W respectively, both crossing Bucharest [4];
- there is sometimes important non-proportionality between amplitudes of spectra corresponding to different stations, from one event to the other (illustrative examples given in Fig's 3 and 4: even in Bucharest, according to Fig. 3, there is non-proportionality of spectral amplitudes, from one event to the other, between the stations INC and CRL);
- the features of attenuation, derived on the basis of statistical analysis (consideration of the attenuation scatter and of the variability of radiation directionality included), were considerably different from one event to the other [4];
- there were important differences of the spectral contents (dominant frequencies, corner frequencies etc.) from one recording station to the other during a same event, as well as (for some stations) from one event to the other (illustration: especially the data of Fig. 3);
- in spite of the fact that the ground conditions are the same for all directions of oscillation, there are important differences between spectral ordinates corresponding to different directions for same event and place (the extreme ratios of ordinates reach, or even exceed, for some oscillation periods, the threshold 3.0, as illustrated in Fig.'s 3 and 4);
- when considering sequences of strong motion records due to the sequence of strong earthquakes referred to, a quite systematic positive correlation between magnitude and velocity/acceleration corner periods was observed for the recording stations located in Bucharest (Fig. 5), but this correlation failed for some recording stations located in several other towns of the most severe seismic zones of Romania (Fig. 6) [3], [2], [6];
- in some other cases, a positive correlation between local ground motion intensity and dominant periods could be observed (example: the Cernavodă – Town Hall station, Fig. 4);

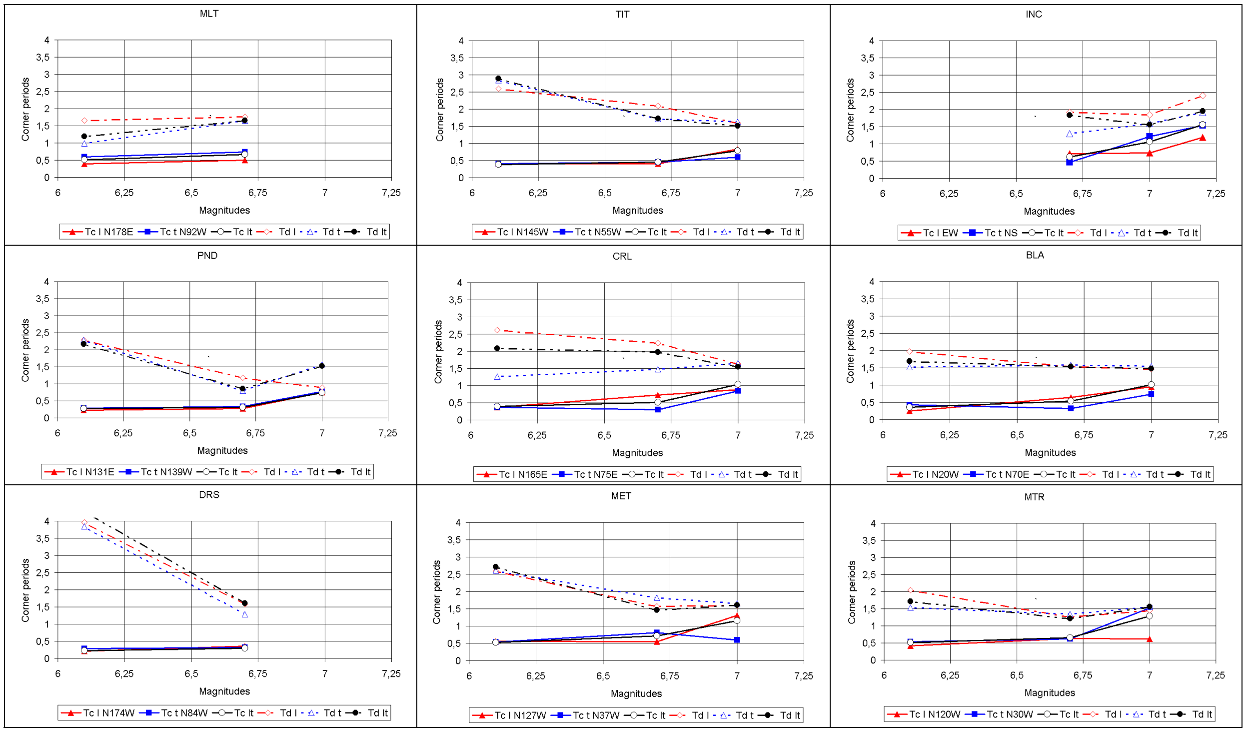


Fig. 5. Corner periods T_C and T_D for stations of Bucharest,
against magnitudes of events of 1977.03.04, 1986.08.30, 1990.05.30, and 1990.05.31.

- in some cases (for some stations and for some events), the dominant (or velocity/acceleration corner- T_C) periods were unusually long (as illustrated by some of the response spectra presented in Fig. 3);
- a relationship between local site conditions and the features of ground motion (consideration of sites with tendency to stability <as in Fig. 4>, or of sites with tendency to variability <as in Fig. 3> of spectral content of ground motion respectively, included) may be emphasized; so, the response spectra determined for different events at a same station show important non-proportionality for the stations of Fig. 3, but higher proportionality for the stations of Fig. 4.

An aspect of primary interest for this paper is represented by the latter aspect referred to, namely by the fact that there are sites for which there was a strong tendency to variability of spectral contents of ground motion and sites for which there was a quite strong tendency to stability of the spectral contents of ground motion. Explaining the reasons for these facts is of obvious interest, because this is directly connected with the chances of anticipating the spectral contents of future strong ground motions.

A first, basic, remark in this respect may be formulated as follows:

- for sites with a strong tendency to variability of the spectral contents, there is no strong contrast for *S* wave propagation velocities at small depth (there is a tendency of gradual increase of this velocity up to important depths);
- for sites with a tendency to stability of the spectral contents, a strong contrast for *S* wave propagation velocities appears at small depths (in the sense of sudden downward increase of velocity at a depth of a few tens of meters).

Note that the plots of Fig. 3 include spectra derived for the record obtained during the 1977 event at the Bucharest – INCERC station (the single ground level station for which a full record was obtained during the destructive earthquake of 1977.03.04).

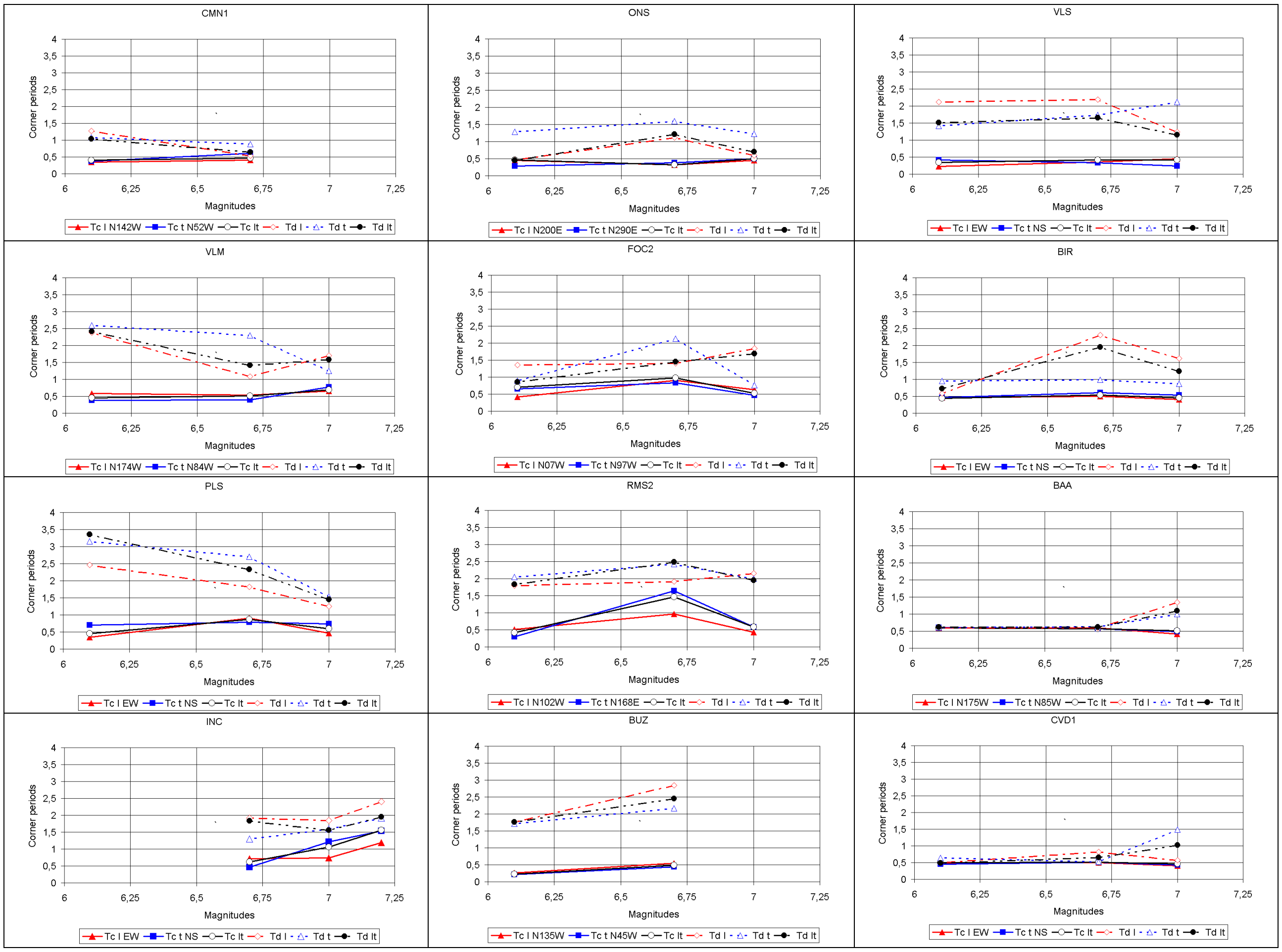


Fig. 6. Corner periods T_C and T_D for stations of province towns, against magnitudes of events of 1977.03.04, 1986.08.30, 1990.05.30 and 1990.05.31.

The examination of the sequences of spectra of Fig's. 3 and 4 makes it possible to emphasize following additional facts:

- for the Bucharest – INCERC station: while the dominant periods were unusually long (around 1.5 s) in 1977, they became relatively short in 1986 (when the long period spectral peaks of more than 1.0 s got a secondary importance) and totally disappeared in 1990;
- for the Focşani and Râmnicul Sărat stations: there was a strong variation of the shape of response spectra, while the longer period components (almost absent at Bucharest – INCERC in 1990) appeared to have been radiated rather towards those latter sites;
- for the Cernavodă - Town Hall station: there was a quite strong tendency to stability of the spectral contents of ground motion, while the dominant periods were rather short (around 0.4 s); on the other hand, in case one considers the sequence of data at hand, there was a tendency to positive correlation between local intensity and dominant motion periods.

The features of response spectra, referred to previously, led to the idea that the sites, stations and sequences of records and spectra of Bucharest – INCERC and of Cernavodă – Town Hall respectively can be dealt with as reference cases, with strongly different features and characteristics. They deserved to be investigated more in depth, using additional instrumental data and processing ways: consideration of microtremor records and of transfer functions of the local geological packages. Anticipating some

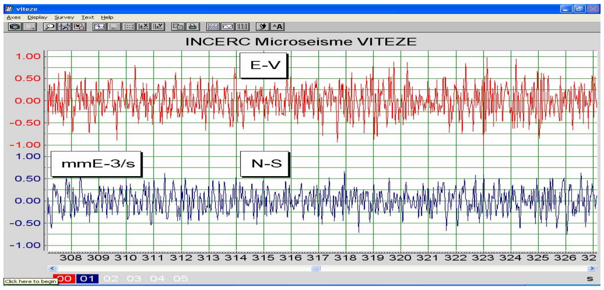
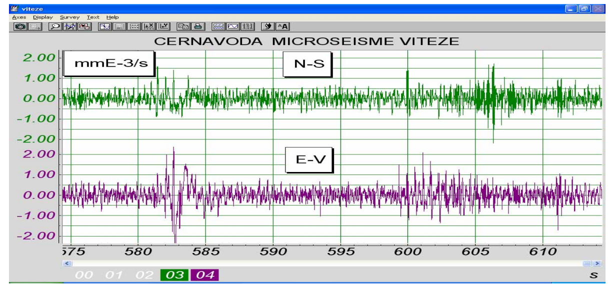
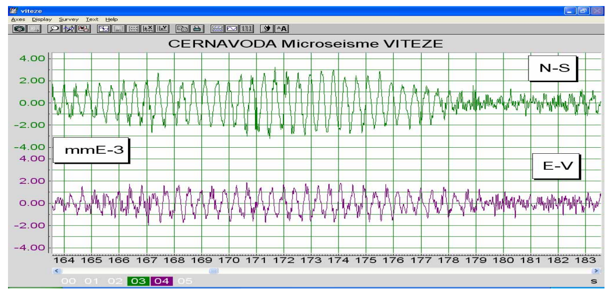


Fig. 7. Sample segment of microtremor record (velocities) *at Bucharest – INCERC site*



Sample (i): chaotic motion



Sample (ii): almost sinusoidal (stronger) motion

Fig. 8. Sample segments of microtremor record (velocities) *at Cernavodă – Town Hall site*

additional data provided subsequently, one can mention the differences related to local conditions: while in case of the Bucharest - INCERC site the increase with increasing depth of the *S* wave propagation velocities is gradual up to important depths (Table 2), in case of the Cernavodă – Town Hall a strong contrast, in the sense of downwards increasing of this propagation velocity, occurs already at small depth.

5. CHARACTERISTICS OF AMBIENT GROUND MOTION. FOURIER ANALYSIS

Microtremors were recorded at several sites in the frame of the research project under way. Given the selection of the sites / recording stations of Bucharest – INCERC and of Cernavodă - Town Hall as reference cases, some samples of the records obtained, as well as of the results of their processing are presented further on.

The records obtained had a length of several tens of minutes. After their visual examination, some sample segments were adopted in order to perform processing, consisting of the determination of running Fourier spectra (RFS) for velocities and displacements of ground motion.

A sample record segment for the ground motion velocity in case of the Bucharest – INCERC site is given in Fig. 7. Note that, according to visual examination, the different sample segments did not present considerably different features for this site. Two sample records are presented further on in Fig. 8 for the Cernavodă - Town Hall site. There appear considerable differences in this case. While for one sample segment the microtremor time history is, as usually, chaotic, there is another segment with much higher amplitudes, for which the motion is almost sinusoidal for velocities and even more so for displacements.

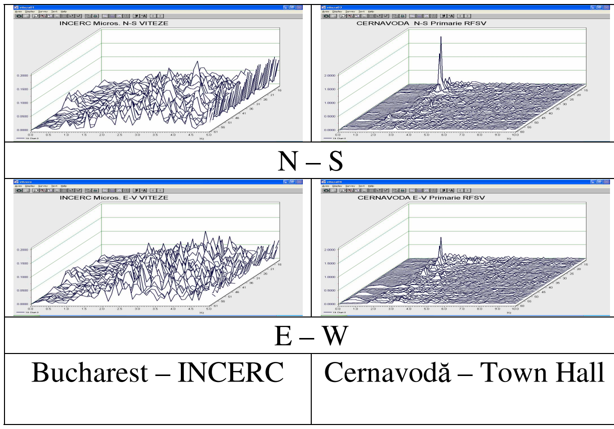


Fig. 9. Running Fourier spectra for microtremor velocities at typical sites

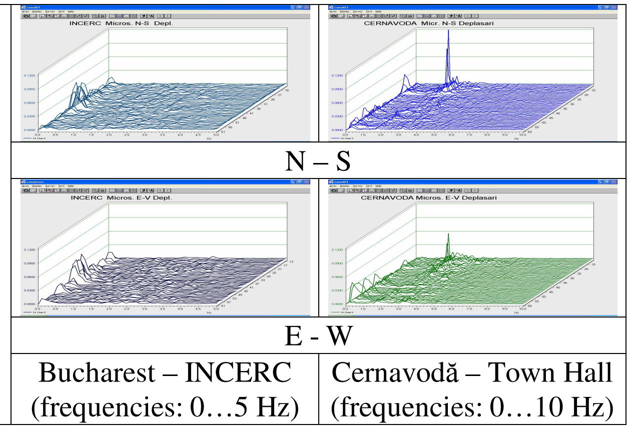


Fig. 10. Running Fourier spectra for microtremor displacements at typical sites

Some of the RFS's derived on this basis are presented in Fig. 9 (for velocities) and in Fig. 10 (for displacements) respectively. The RFS plots are presented in the same figures for both sites, in order to make comparison easier. Their examination permits to derive some conclusions as follows:

- in case of the Bucharest – INCERC site the RFS shape corresponds continually to chaotic motion, with little evidence of dominant frequencies; there are intervals of time for which there appear quite important spectral peaks for very low frequencies (in the range of 0.15 … 0.2 Hz), which correspond to magnified spectral components observed for remote earthquakes (of Asia or Mexico) and which were present, to some extent, also for Vrancea earthquakes (especially for displacements); there are no relevant spectral peaks to correspond to the main spectral peaks for the strong motions recorded (Fig. 3, first column);
- in case of the Cernavodă – Town Hall site the RFS shape puts to evidence time segments for which the motion is chaotic, but also segments for which there appear strong spectral peaks (with a frequency of about 2.4 Hz, corresponding very well to the strong spectral peaks of Fig. 4, last column); there are thus intervals of time for which there appear strong and sharp spectral peaks for a frequency coinciding with the (stable) predominant frequency observed for the strong motion records; there are also intervals of time for which there appear quite important spectral peaks for very low frequencies (in the range of 0.2 … 0.25 Hz), which would correspond to the fundamental frequencies of geological packages of a thickness in the range of thousands of meters);
- it may be thus stressed that in both cases (more obviously in case of the Bucharest – INCERC site) one may remark, especially for the displacements, very low frequency peaks, which are in accordance with the spectral features observed for remote (especially extra-European) earthquakes; this aspect is discussed again in the next section, in connection with transfer functions derived.

6. ANALYSIS OF TRANSFER FUNCTIONS

The dynamic theory of the motion of the upper geological package is, as known, widely accepted and used. According to this theory the upper package behaves like a dynamic system and consequently modifies the spectral content of the input motion applied at the base rock level. The theory is consistent, but there is an unanswered problem: where to postulate the interface with the base rock? In case one meets a sharp contrast for the *S* wave propagation velocity (in the sense of increase of velocity with increasing depth) at the interface of some adjacent geological layers, it appears to be reasonable to accept the corresponding depth as the depth of the base rock. But, how to proceed in case of absence of the sharp contrast referred to?

The approach presented at this place was conceived as a numerical experiment conducted in a parametric way, aimed at adding to the knowledge at hand in this field. The main case study undertaken refers to the Bucharest – INCERC type site, where the strong variability of the spectral content put to evidence by the response spectra of Fig. 5 occurred. Combining data at hand concerning the geological conditions, [1] (ch. 5), as those used in [5], one defined the data concerning the geological conditions as in Table 2.

The parametric analysis concerning the transfer function of the upper geological package was conducted as follows: the package considered consisted initially of the first (upper) layer only, then of the first two layers only, then of the first three layers only, … finally of all the eight layers defined according to Table 2.

The outcome of the computations performed is represented in graphic terms in Fig. 11 (log – log scale, abscissa representing log *T*, ordinate representing the logarithm of the transfer function modulus). The examination of these plots makes it possible to emphasize following aspects:

- the transfer function derived for the case of considering a single layer (plot up left) corresponds obviously to the analytical solution;
- increasing gradually the number of layers considered leads to a gradual increase of the fundamental period characterizing the transfer function;
- the shape of the transfer function changes considerably when the number of layers considered changes; a certain tendency to stability of the transfer function shape appears in case one considers more than four layers (when the interface with stronger contrast at a depth of 600 m, after the fourth layer, is exceeded);
- in case one considers a deep geological package, one remarks that the transfer function has several main peaks of comparable importance, which means that, in this case, the spectral characteristics of ground motion will be determined primarily by the features of the input disturbance;
- the peaks of the transfer function (numbered leftwards) in case of considering all eight layers, up to a depth of 2800 m, present an interesting correspondence with instrumental data at hand: the first peak (period: ~ 5.7 s) corresponds fairly to the dominant periods of some 6 s, observed for records of remote earthquakes and to the frequencies of 0.15 … 0.2 Hz of the peaks of Fig. 10 (left column); the fourth peak (period: ~ 1.5 s) corresponds fairly to the main spectral peak of Fig. 3 for the 1977 event; the last important peak to the left (period: ~ 0.7 s) corresponds fairly to the main spectral peaks of Fig. 3 for the 1986 and 1990 events respectively.

Coming now to the site of Cernavodă – Town Hall, the geological stratification is considerably different. One meets, at a depth less than 30 m, a strong (fivefold) jump of the *S* wave propagation velocity, from 200 to 950 … 1350 m/s (after a depth of about 200 m, this value oscillates around 2000 m/s). Starting from this situation, an exercise concerning the sensitivity of the transfer function to basic data under similar conditions was imagined. One considered a constant upper layer of 20 m, with a density of 1.8 t/m^3 and a propagation velocity of 200 m/s, followed by a second (homogeneous) layer with a density of 2.4 t/m^3, with parametrically variable thickness (from 50 to 1000 m) and propagation velocity (from 1000 to 2000 m/s). The outcome of computations is partially presented in Fig. 12 (log – log representation used again).

Looking at the plots presented, one may remark:

- the stability of the oscillation periods corresponding to the transfer function peaks; this represents an explanation of the tendency to stability put to evidence by the sequence of response spectra at hand;

TABLE 2
INPUT DATA FOR BUCHAREST – INCERC TYPE SITE

No. of layer, k	Layer depth intervals (m)		Layer thick-ness, h_k (m)	Densities ρ_k (t/m^3)	S wave propagation vel. c_s (m/s)
	Min.	Max.			
1	0	70	70	1.6	320
2	70	130	60	1.8	420
3	130	200	70	2.2	640
4	200	600	400	2.2	700
5	600	1000	400	2.2	1340
6	1000	2000	1000	2.6	2040
7	2000	2400	400	2.4	1710
8	2400	2800	400	2.8	2650

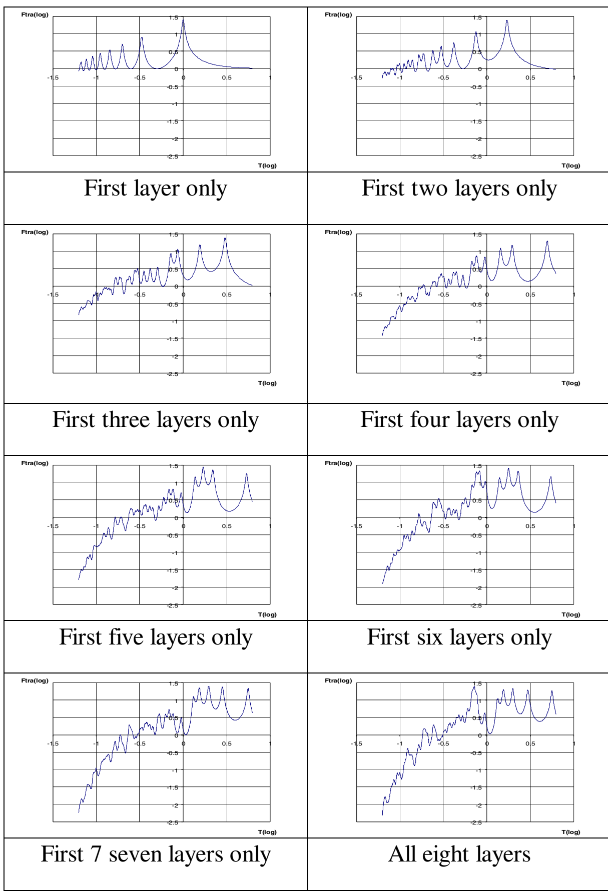


Fig. 11. Results of stepwise analysis of transfer function for Bucharest - INCERC site type

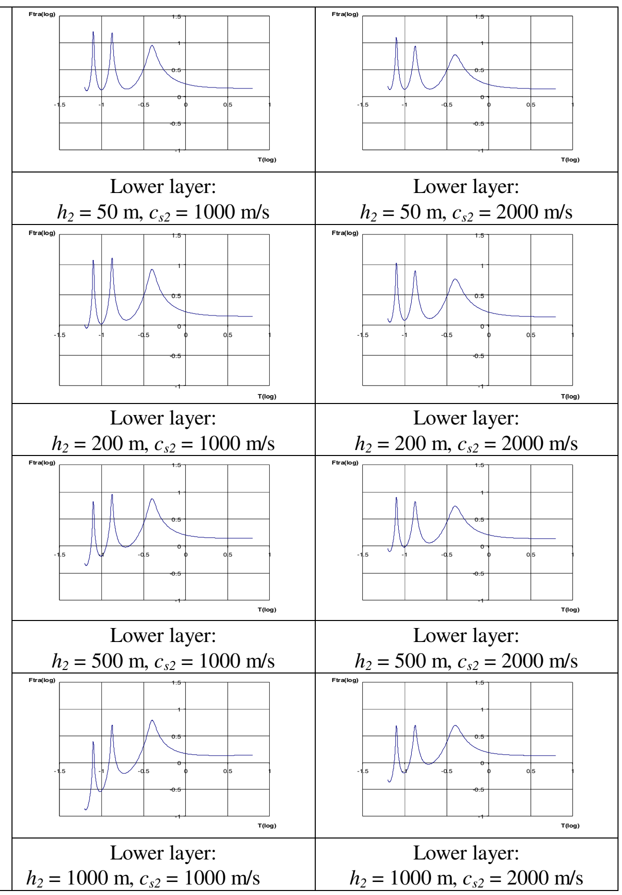


Fig. 12. Results of parametric analysis of transfer function for Cernavodă – Town Hall site type

- a quite stable fundamental period, very close to the dominant periods of the column of Fig. 4.

Looking at the plots presented, one may remark:

- the stability of the oscillation periods corresponding to the transfer function peaks; this represents an explanation of the tendency to stability put to evidence by the sequence of response spectra at hand;
- a quite stable fundamental period that is very close to the dominant periods of the column of Fig. 4.

Besides the scalar transfer function, referred to above, spatial transfer functions, depending also on the downwards abscissa (i.e. complex ratios of motion amplitude at various depths to homologous motion amplitude at base rock level) were determined for several sites. It turned out that, for stratifications at hand, it is necessary to consider deep geological packages in order to derive, in an analytical way, conclusions on the dynamic characteristics of local geology.

7. RECONCILIATION OF RESULTS

The outcome of the three different approaches presented (analysis of response spectra, deriving of microtremor RFS's, transfer function analysis) was to a rather high extent convergent and encouraged the authors to derive some conclusions concerning the expected spectral features of ground motion during strong earthquakes to come. They are as follows:

1. One can consider, as possible reference cases for local conditions two (perhaps extreme) situations:

a) the presence of a strong (positive) jump of *S* wave propagation velocity at a small depth;
b) a gradual increase of *S* wave propagation velocities up to important depths.

2. In case of sites of type (a), the local conditions play a dominant role for the spectral content of ground motion and consequently there is a tendency to stability of the dominant frequencies of ground motion. Consequently, there are encouraging chances for their anticipation. In case of sites of type (b), there is a tendency to variability of the spectral content of ground motion, while the main role in determining the spectral content tends to be played by the focal mechanism and the features of radiation / attenuation over long distances. Consequently, there are much lower chances of anticipation of the spectral features of ground motion, which could significantly differ in future from those observed to date (important case: the City of Bucharest).

8. FINAL REMARKS

The developments of the paper make it possible to derive some conclusions and recommendations of wider interest:

1. The rules of specification of local ground conditions, given in several codes, which rely on the consideration of the soil quality up to a depth in the range of a few tens of meters (as e.g. those of [10]) are non-realistic. It is by far not the same in case after a depth of, say, 60 m of the softer layers, the stratification is continued by rather similar material or one meets a hard base rock.
2. In case one has to specify the seismic conditions for the site of an important structure / facility, it is recommendable to jointly consider at least:

- data related to the (sequences of) strong motion response spectra at site (if available) or to response spectra at sites for which local conditions are believed to be rather similar;
- data related to microtremors;
- data on the local geological / geophysical characteristics up to important depths (if possible, in the range of kilometers), deriving on this basis specific transfer functions, possibly in a parametric frame.

It is recommendable to look for a reconciliation of conclusions derived on the basis of such alternative approaches, based mainly on expert judgment.

ACKNOWLEDGMENTS

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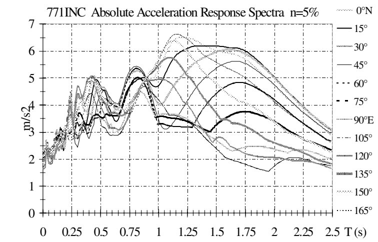
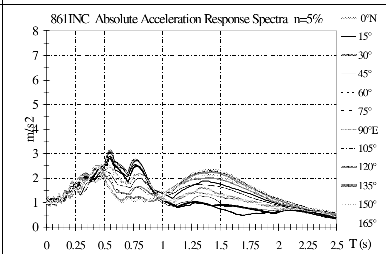
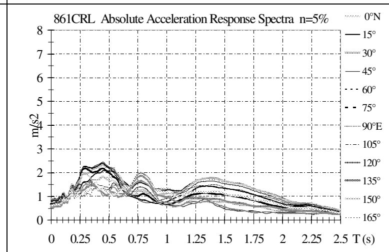
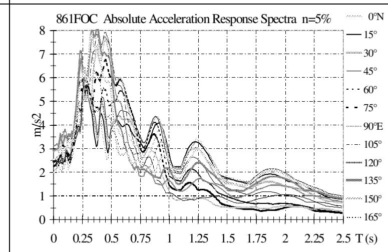
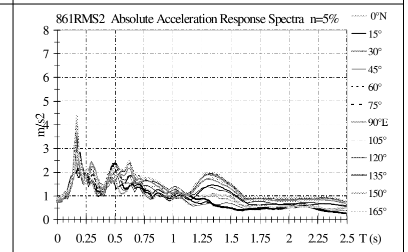
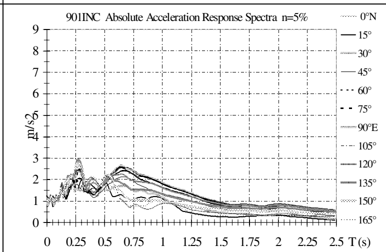
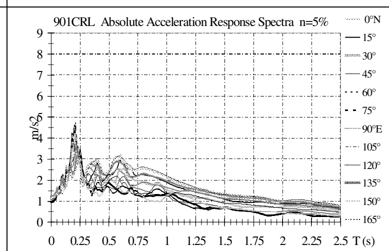
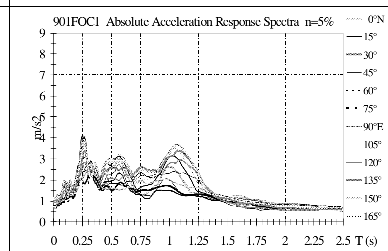
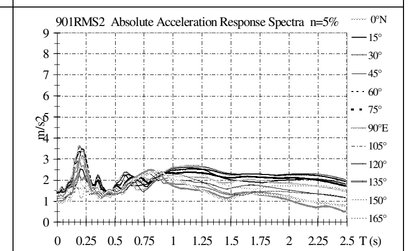
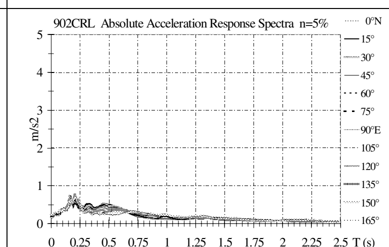
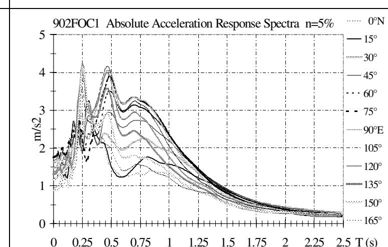
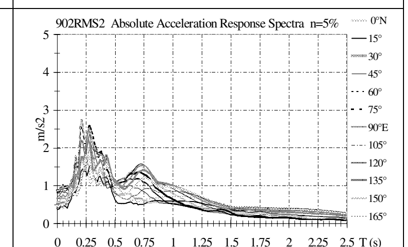
1977.03.04 $M_{GR} = 7.2$		?	?	?
1986.08.30 $M_{GR} = 7.0$				
1990.05.30 $M_{GR} = 6.7$				
1990.05.31 $M_{GR} = 6.1$	?			
Stations →	a) Bucharest – INCERC (INC)	b) Bucharest – Carlton (CRL)	c) Focşani (FOC)	d) Rm. Sărat 2 (RMS)

Fig. 3. Response spectra (absolute accelerations, 12 directions for stations of category (b)

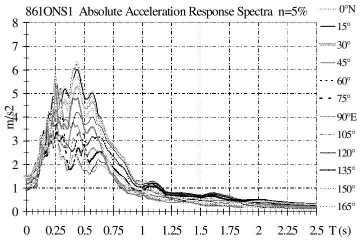
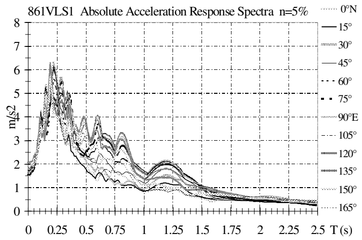
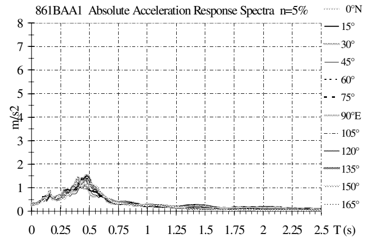
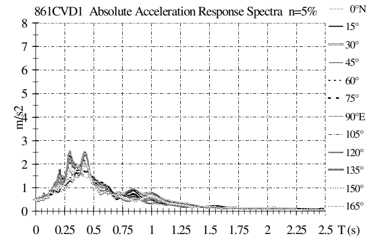
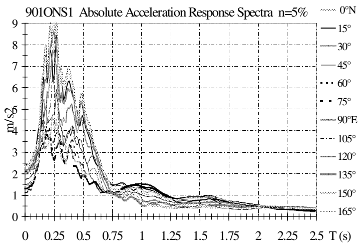
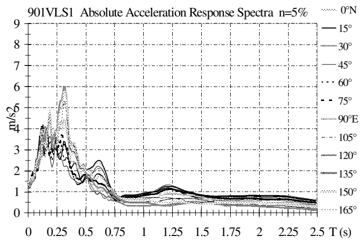
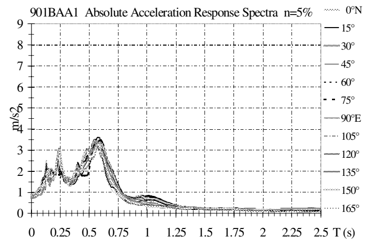
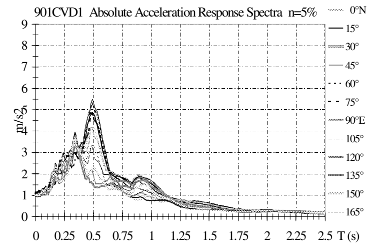
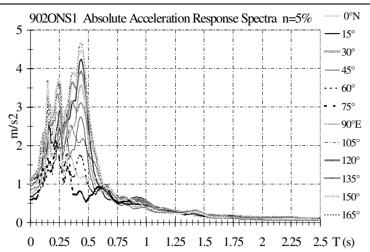
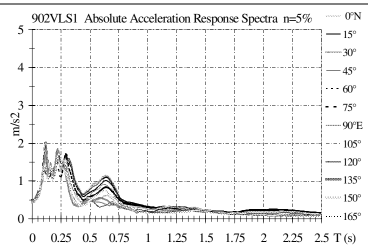
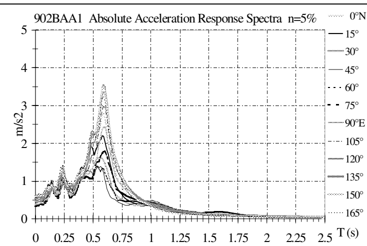
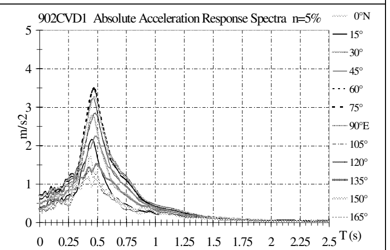
1977.03.04 $M_{GR} = 7.2$	?	?	?	?
1986.08.30 $M_{GR} = 7.0$				
1990.05.30 $M_{GR} = 6.7$				
1990.05.31 $M_{GR} = 6.1$				
Stations →	a) Oneşti (ONS)	b) Vaslui (VLS)	c) Baia – Dobrogea (BAA)	d) Cernavodă (CVD)

Fig. 4. Response spectra (absolute accelerations, 12 directions) for stations of category (a)