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Seismic Intensity and Hazard Quantifications, Versus Some Earthquake Engineering Requirements

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SEISMIC INTENSITY AND HAZARD QUANTIFICATIONS, VERSUS SOME EARTHQUAKE ENGINEERING REQUIREMENTS

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CONTENTS

1. INTRODUCTION

Object of talk: some views of a structural engineer involved in earthquake protection, on specific topics of engineering seismology and seismic risk assessment.

Bulk of talk: discussion on the features of ground motion in connection with the processing and interpretation of strong motion instrumental data.

Consequence: pledge for a radical reconsideration of the concept of seismic intensity, providing a way of characterization of ground motion that is compatible with the reequirements of engineering activities.

Solution envisaged: setting up of a framework for joint efforts of seismologists and engineers (e.g. for Europe: a Joint Working Group under the auspices of ESC and EAEE).

2. SOME COMMENTS ON THE FRAMEWORK OF SEISMIC RISK ANALYSIS

Specific philosophy: recognition of the concept of seismic risk and of its scientfic and social importance.

Basic goal assumed: definition and evaluation of risk in quantitative terms.

Basic concepts used:
- elements at risk;
- seismic action;
- seismic hazard;
- adverse earthquake effects;
- seismic vulnerability;
- exposure;
- seismic risk;
- earthquake scenario.

SOME COMMENTS ON THE BASIC CONCEPTS

Concepts referred to	*On the definitions*	*Addenda*
Elements at risk	any social value that can be adversely affected by earthquake incidence	the diversity of *elements at risk* is unlimited; they must be identified and specified in each specific case
Seismic action	motion due to an earthquake, which can affect elements at risk	the *action* can be considered at source level or at site level, as suitable for risk analysis
Seismic hazard	expectancy of a sequence of cases of incidence of seismic action	the relationship between *hazards* at source and site levels requires consideration of attenuation
Adverse earthquake effects	effects due to the incidence of seismic action	the *effects* are specific to the elements at risk
Seismic vulnerability	proneness of elements at risk to undergo adverse effects in case of incidence of seismic action	*vulnerability* is usually considered in relation to a single case of incidence of seismic action; in the opposite case, one can consider evolutionary vulnerability

Exposure (of elements at risk)	extent to which elements at risk are exposed	*exposure* can be total and permanent, or it can be partial and variable
Seismic risk	expectancy of a sequence of cases of incidence of adverse seismic effects	*seismic risk* is in principle the final objective of analyses in this field
Earthquake scenario	imaginary process of earthquake occurrence and of effects produced, considered to be relevant for possible actual events	An *earthquake scenario* is a pragmatic substitute for proper risk analysis, which is seldom feasible in practice

MAIN CALCULATION STEPS IN RISK ANALYSIS

1. The starting approach accepts several simplifying assumptions, like:
   - unique location on elements a risk;
   - no chain effects;
   - no cumulative effects of successive earthquakes considered)

In this case, some relatively simple convolutions are to be performed:

[*HAZARD AT SOURCE LEVEL*] * [*ATTENUATION*] → [*HAZARD AT SITE LEVEL*]

[*HAZARD AT SITE LEVEL*] * [*VULNERABILITY*] (* [*EXPOSURE*]) → [*RISK*]

2. In practice, much more complex tasks may occur, in cases some generalizations of assumptions are necessary.

Consider as examples:
   - risk analysis for regional networks or for urban systems;
   - various possible chain effects;
   - cumulative effects of successive earthquakes.

Some comments on hazard representation and assessment:

- usually, hazard representation and assessment is dealt with in scalar terms, i.e. the variability of a single parameter, like seismic intensity or peak ground acceleration is taken into account;

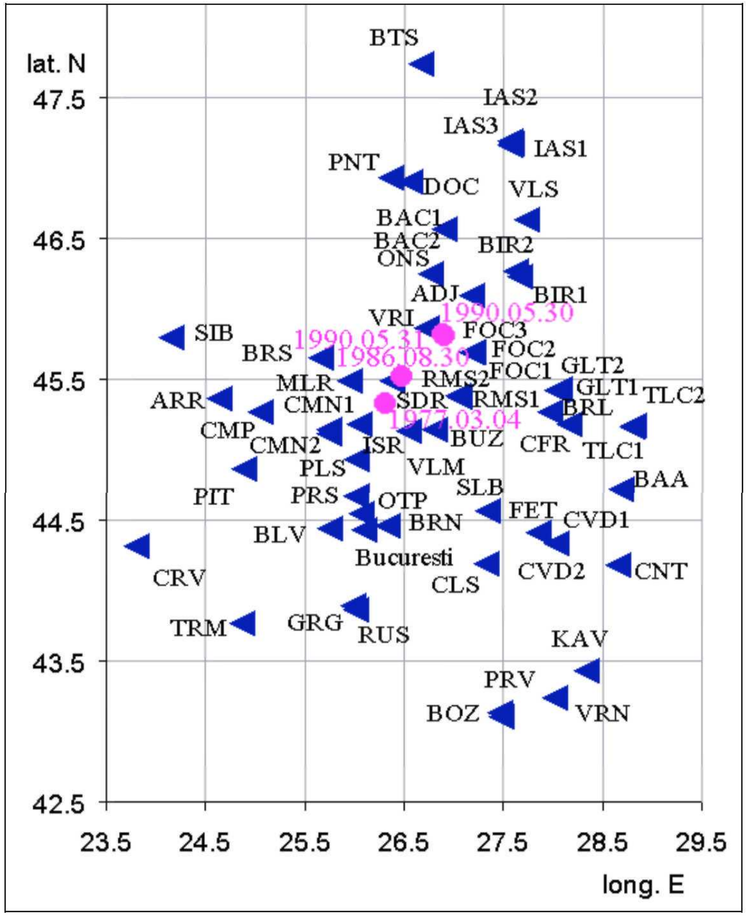
- in fact, looking at information at hand, a multi – dimensional variabilty is revealed;

- this raises the problem of considering multi – dimensional spaces for variability representation [Sandi, 2006, 2009], with corresponding adaptation of risk analysis techniques.

3. SOME LESSONS
FROM THE RECENT STRONG VRANCEA EARTHQUAKES

General data on the strong earthquakes referred to

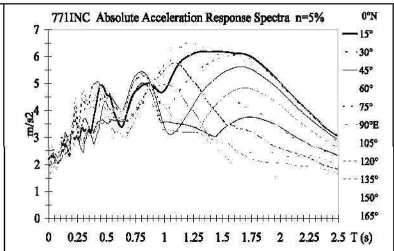
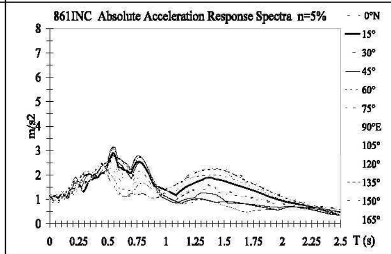
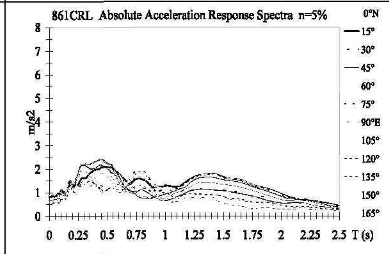
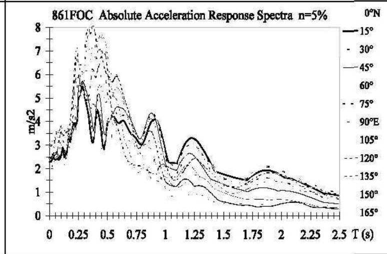
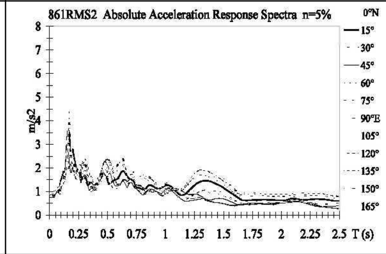
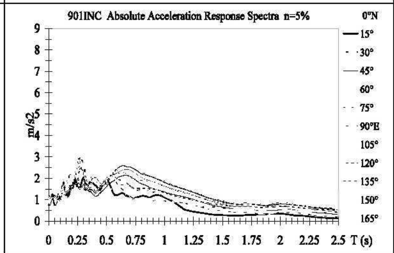
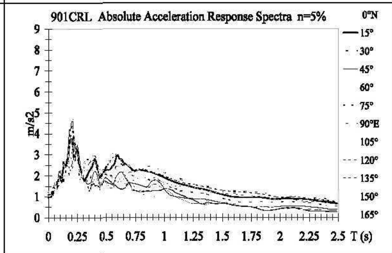
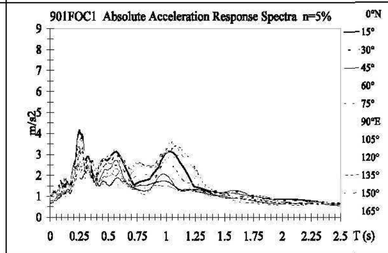
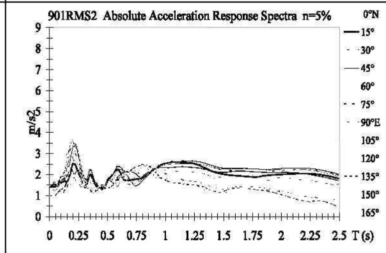
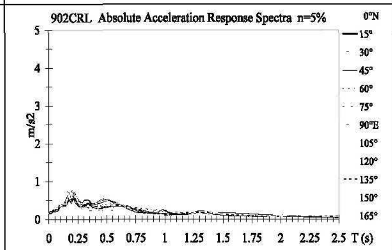
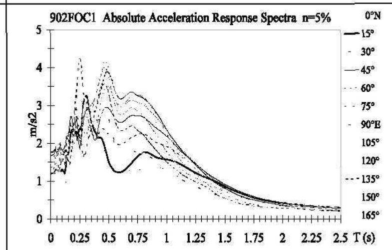
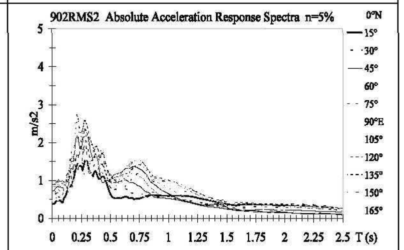
No	Earthquake	Lat. N	Long. E	Code Earthquake	h (km)	Date	M_w
1	Vrancea M_{GR} = 7.2	45,34	26,30	771	109	1977.03.04	7,5
2	Vrancea M_{GR} = 7.0	45,53	26,47	861	133	1986.08.30	7,3
3	Vrancea M_{GR} = 6.7	45,82	26,90	901	91	1990.05.30	7,0
4	Vrancea M_{GR} = 6.1	45,83	26,89	902	79	1990.05.31	6,4



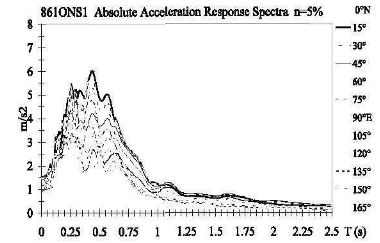
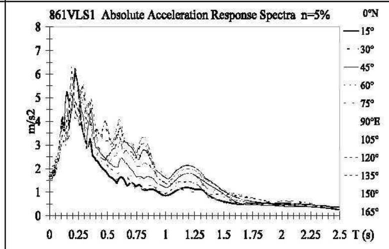
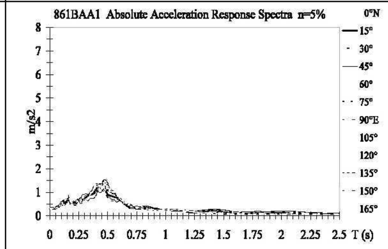
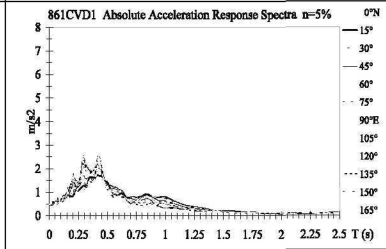
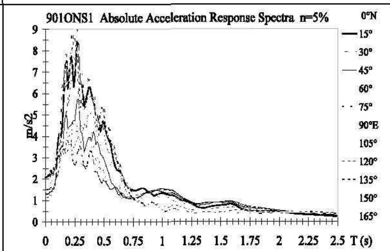
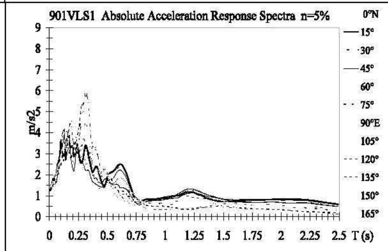
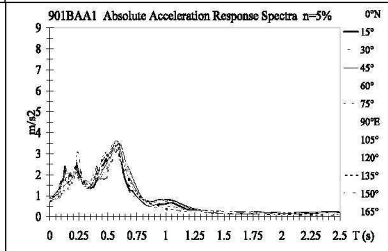
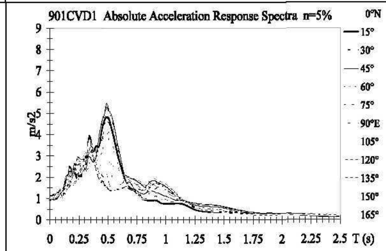
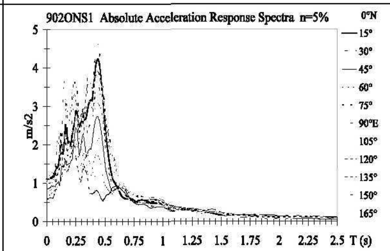
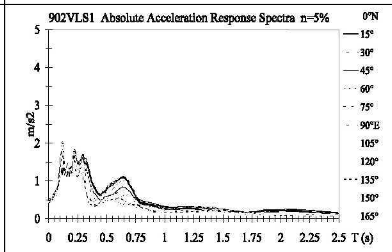
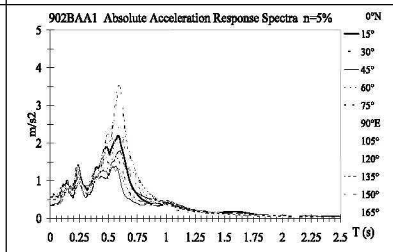
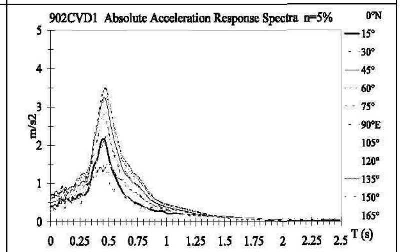
Analogical accelerographic network of the parts of Romania and Bulgaria affected primarily by Vrancea earthquakes

SOME RELEVANT RESULTS OF PROCESSING OF ACCELEROGRAPHIC DATA

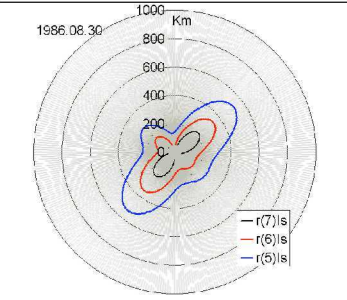
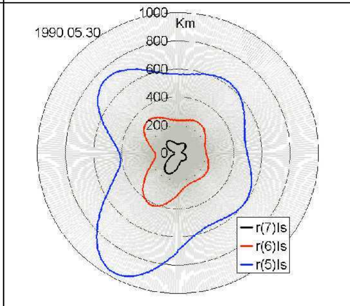
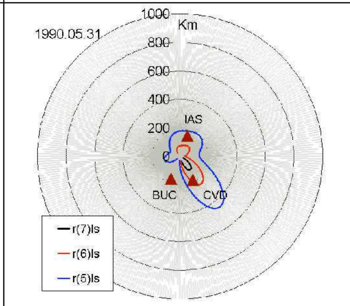
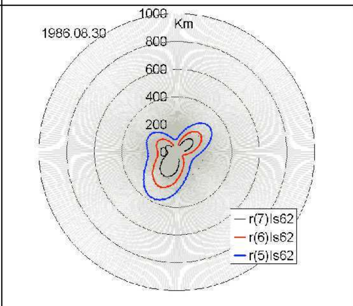
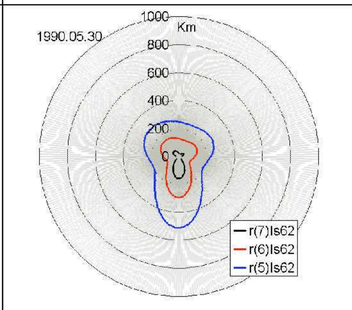
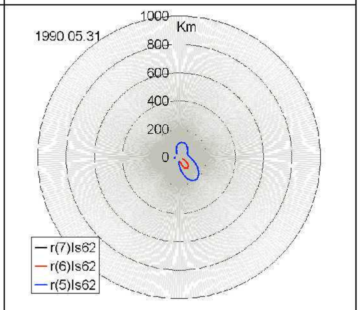
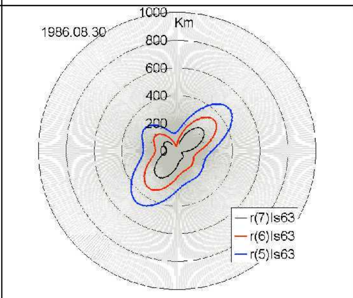
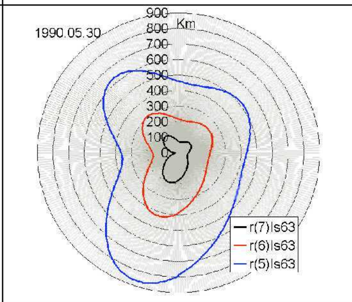
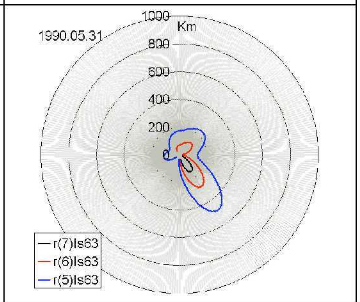
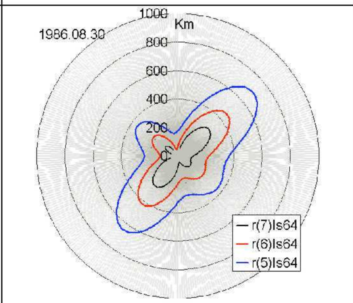
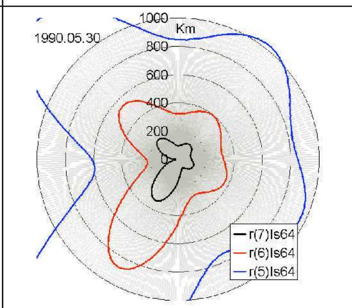
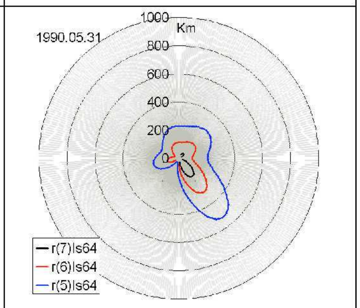
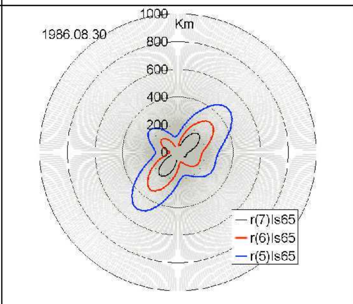
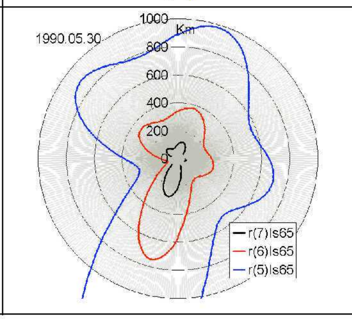
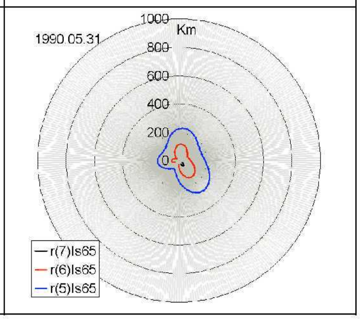
[Sandi & al., 2004a, 2004b]:

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)

Sequences of response spectra (12 directions) for stations of category (a) (strong tendency of variability of the spectral content of ground motion)

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)

Sequences of response spectra (12 directions) for stations of category (b)
(strong tendency of stability of the spectral content of ground motion)

	1986.08.30, $M_{GR} = 7.0$	1990.05.30, $M_{GR} = 6.7$	1990.05.31, $M_{GR} = 6.1$
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)			

Directivity of attenuation, for various events and frequency bands
(common scale, up to epicentral distance of 1000 km)

SUMMARY AND CONCLUSIONS

1. On the spectral contents of ground motion:

- there were, in broad terms, stations of two categories:
  a. with strong variation of spectral variability of ground motion from one event to the other;
  b. with strong stability of dominant frequencies of ground motion;

- the local ground conditions were, in broad terms, as follows:
  a. for stations of category (a), no strong contrast of *S* wave velocities at interfaces of successive layers, up to considerable depth;
  b. for stations of category (b), strong contrast of *S* wave velocities at interfaces of successive layers, already at depths of a few tens of meters;

- conclusions:
  a. for stations of category (a), the spectral contents of ground motion was influenced mainly by source mechanism and long distance wave radiation;
  b. for stations of category (a), the spectral contents of ground motion was influenced mainly by local conditions.

2. On radiation and attenuation:

- unexpectedly, attenuation was faster in case of the deeper source of 1986.08.30 than in that of 1990.05.30, when it was particularly slow;

- the radiation directivity was different from one event to the other; while in case of the event of 1986.08.30 it was close to that of the destructive earthquakes of 1940.11.10 and 1977.03.04, in case of the events of 1990 the main radiation azimuths deviated counter-clockwise;

- especially in case of the event of 1990.03.30, the radiation directivity was different for different spectral bands.

3. On the effects upon structures:

- the importance of the spectral contents of ground motion for the effects upon structures was obvious (collapses in 1977 of high-rise buildings, corresponding to the relatively long dominant period of ground motion n Bucharest);

- it turned out that an attempt of radical revision of the concept of seismic intensity, to account for the needs of engineering activities is necessary.

4. CHARACTERIZATION AND QUANTIFICATION OF SEISMIC ACTION (AT SITE LEVEL)

Two main views of the problem, related to different historical times:

a) pre – instrumental, pre - engineering view:

   i. vague definitions;

   ii. rough and uncertain quantifications (most popular quantification: *ground motion intensity*);

b) modern view, relying on mathematical modelling and on instrumental information:

   i. connected to an analytical approach to structural performance and structural risk and safety;

   ii. based on the availability of rich and high quality instrumental data.

Main source of data and results presented subsequently:

- some recent contributions of the Russian school of seismology (Moscow Institute of Physics of the Earth of the Russian Academy of Sciences);
- some contributions of a group pertaining to two Bucharest institutes;

put together in the frame of the Project [Sandi & al., 2006], [Aptikaev & al., 2008a], [Sandi & al., 2010].

QUANTIFICATION OF SEISMIC ACTION ON STRUCTURES

(Studies related to a project sponsored by NATO, in the frame of the Program “Science for Peace”, 2005 – 2008.)

Main contributors to the Project:

Romania:

Horea Sandi, Project Director & Editor,
- Academy of Technical Sciences of Romania & Institute of Geodynamics of the Romanian Academy,

Ioan Sorin Borcia - National Building Research Institute, Bucharest.

Russian Federation:

Felix F. Aptikaev - Institute of Physics of the Earth of the Russian Academy of Sciences,
Olga O. Erteleva - Institute of Physics of the Earth of the Russian Academy of Sciences.

Republic of Moldova:

Vasile Alcaz - Institute of Geology and Seismology of the Academy of Sciences of the Republic of Moldova.

The participants agreed upon the need of updating the scale EMS-98 [Grünthal, 1998].

One main point: *to develop and introduce appropriate instrumental criteria.*

SOME RECENT STUDIES AND RESULTS OF THE RUSSIAN SCHOOL

An older reference:

Average values of kinematic parameters according to the MSK 1976 scale

MSK intensity	*PGA* (cm/s^2)	*PGV* (m/s)	PS_MD (mm)
VI	50	4	2
VII	100	8	4
VIII	200	16	8
IX	400	32	16

The developments of [Aptikaev & al., 2008b] refer, among other, to following ranking system (of increasing relevance) of the scales pertaining to the Mercalli family:

Class	*Characterization*
Nominal scales	The use of that scale permits distinguishing objects and phenomena from one another, but no comparison is possible in any one parameter. For example, one nominal scale is a catalog of typhoons with indication of their names.
Class scales	In these scales the orderliness of the original set *A* determines uniqueness with which *A* is mapped into *B* apart from a monotone increasing transformation of the original set *A* into *B*. However, no quantitative measure is available for ordinal scales. Examples of ordinal scales are the Beaufort scale for wind on land and at sea and Mohs' scale for the hardness of minerals. In this 10-grade scale, the hardness standards are ten minerals, talc being the softest and diamond the hardest.
Ordinal scales	In these scales the orderliness of the original set *A* determines uniqueness with which *A* is mapped into *B* apart from a monotone increasing transformation of the original set *A* into *B*. However, no quantitative measure is available for ordinal scales.
Interval scales	In these scales, the grades are uniform in an independent parameter. Such a scale admits of quantitative operations performed on differences between grades. For example, the distance between seismic intensity III and IV is equal to that between intensities VII and VIII, when the independent parameter is log ground acceleration.
Ratio (or absolute) scales	In it, numerical estimates of the effect can be obtained permitting all arithmetic operations on measurement results. Examples of such scales are the instrumental scale for hardness of minerals measured in kgf/mm^2 (instead of Mohs' scale), the instrumental scale for wind velocity in m/s (instead of the Beaufort scale), and the earthquake magnitude scale. Any ratio scale has a zero, and there are no essential bounds on the lowest and the highest values. Such scales are sometimes called *absolute scales*.

While stating that the magnitude scale is an absolute scale, it is concluded in that paper that "The seismic scales of the Mercalli family are in the class of interval scales".

* * *

Outcome of statistical analysis of instrumental data for various macroseismic intensities [Aptikaev, 2005] (slightly updated)

$\lg A$ ($\equiv PGA$), cm/s^2 = $-0.755 + 0.4\,I \pm 0.39$ (0.25) (correlation coefficient: 0.82) (1)

$\lg V$ ($\equiv PGV$), cm/s = $-2.23 + 0.47\,I \pm 0.33$ (0.20) (correlation coefficient: 0.84) (2)

$\lg D$ ($\equiv PGD$), cm = $-4.26 + 0.68\,I \pm 0.65$ (0.33) (correlation coefficient: 0.81) (3)

$\lg P$, cm^2/s^3 = $-2.22 + 0.87\,I \pm 0.49$ (0.41) (correlation coefficient: 0.89) (4)

Quantities under "±" mean standard deviations, related both to intensity and ground motion parameters estimations. In parentheses are given values for intensities $I > 6$.

It turns out that the average values obtained for a jump of one intensity unit are:

- for peak ground accelerations, $10^{0.4} \approx 2.51$ ≈ 2.5;
- for peak ground velocities, $10^{0.47} \approx 2.95$ ≈ 3.0;
- for peak ground displacements, $10^{0.68} \approx 4.79$ ≈ 4.8;
- for peak wave kinematic power (as also for the product of peak ground acceleration and peak ground velocity), $10^{0.87} \approx 7.41$ ≈ 7.5.

SOME RECENT STUDIES AND RESULTS OF THE ROMANIAN GROUP

Two basic developments were initiated successively:

- on one hand, definition of *destructiveness spectra* (which can be extended to tensorial characteristics), [Sandi, 1979], [Sandi, 1980], which represent a generalization of Arias' approach [Arias, 1970] and was modified in [Sandi & Floricel, 1998];

- on the other hand, definition of *spectrum based intensity*, based on linear response spectra for acceleration and velocity [Sandi, 1986].

These two approaches were merged in [Sandi & Floricel, 1998]. These latter developments are used as a starting point in following presentation.

In setting up these proposals, it was intended to provide a best possible compatibility with classical macroseismic scales, providing, at the same time, a suitable flexibility for situations in which there is a need for more detailed information than just a global intensity measure.

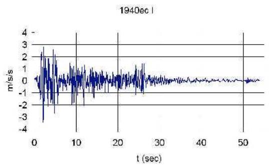
The system of criteria developed in [Sandi & Floricel, 1998] is presented in next table. Detailed analytical relations involved in these definitions are given in [Sandi & Floricel, 1998]. It may be noted in this respect that the definitions referred to included:

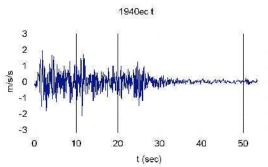
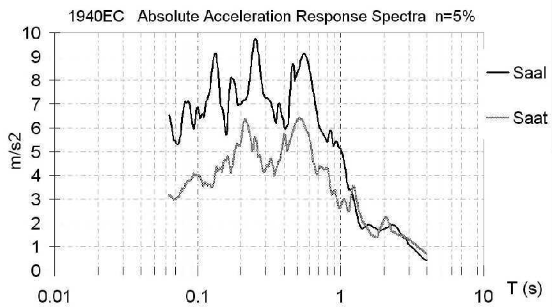
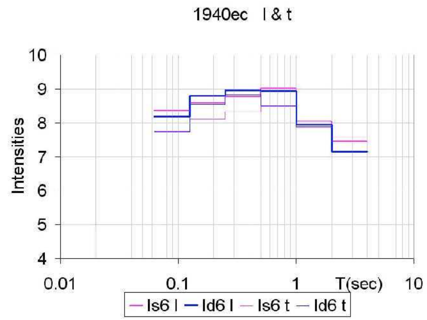
System of instrumental criteria for intensity assessment

Name	Symbols used for intensities: * global ** related to a frequency *** averaged upon a frequency interval			Source of definition / comments
	*	**	***	
Spectrum based intensities	I_S	$i_s(\varphi)$	$i_s^{\sim}(\varphi', \varphi'')$	Linear response spectra for absolute accelerations and velocities / use of *EPA*, *EPV*, redefined as *EPAS*, *EPVS* respectively (see relations (10)); averaging rules specified
Intensities based on Arias' type quadratic integral of ground motion acceleration	I_A	$i_d(\varphi)$	$i_d^{\sim}(\varphi', \varphi'')$	Quadratic integrals of acceleration of ground (for I_A), or of pendulum of natural frequency φ (for $i_d(\varphi)$) / extensible to tensorial definition; averaging rules specified
Intensities based on quadratic integrals of Fourier images of ground motion acceleration	I_F ($\equiv I_A$)	$i_f(\varphi)$	$i_f^{\sim}(\varphi', \varphi'')$	Quadratic integrals of Fourier image of acceleration (for I_F), or quadratic functions of Fourier images (for $i_d(\varphi)$) / extensible to tensorial definition; averaging rules specified

Illustrative ground motion characteristics

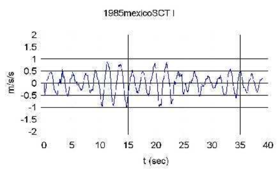
<table>
<tr><th rowspan="2">No</th><th rowspan="2">General data on event and on record site</th><th colspan="3">Characteristics of ground motion along two orthogonal horizontal directions</th><th rowspan="2">Magnitudes and global intensities</th></tr>
<tr><th>Accelerograms</th><th>Response spectra for absolute acccelerations (5% critical damping)</th><th>Intensity spectra : $i_s^{\sim}(\varphi', \varphi'')$, red, and $i_d^{\sim}(\varphi', \varphi'')$, blue, averaged upon 6 dB intervals</th></tr>
<tr><td>1</td><td>Source:
USA, Ca, Imperial Valley
1940.05.18

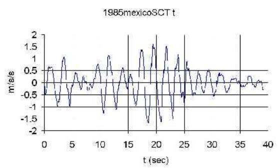
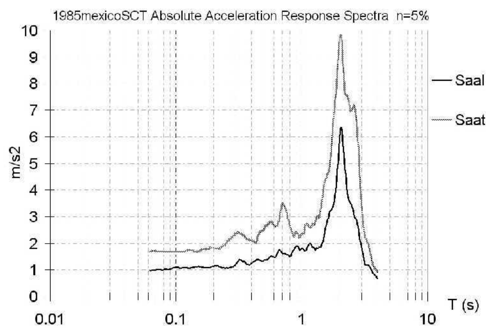
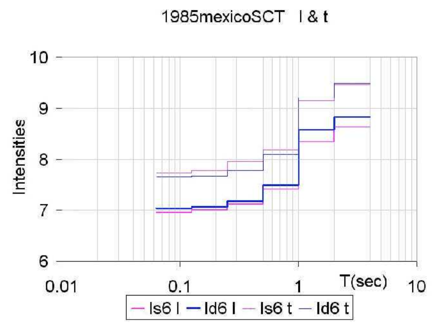
Record site:
El Centro</td><td>


</td><td>
</td><td>
</td><td>M_S: 7.0

I_S: 8.01 (8.18, 7.80)

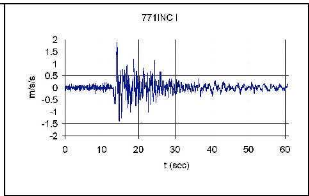
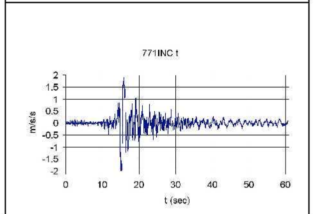
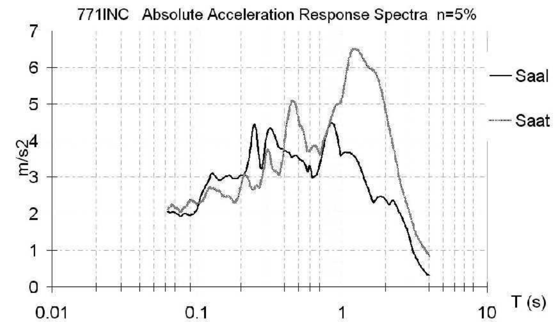
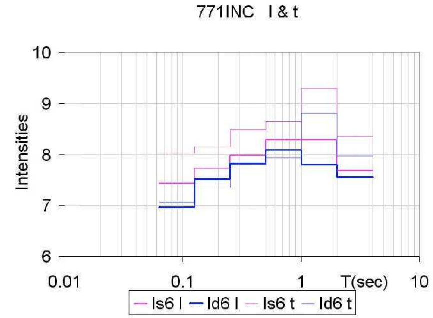
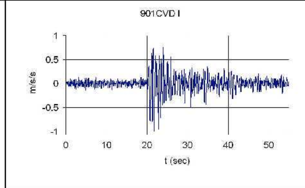
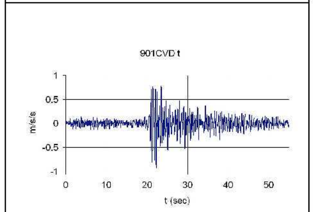
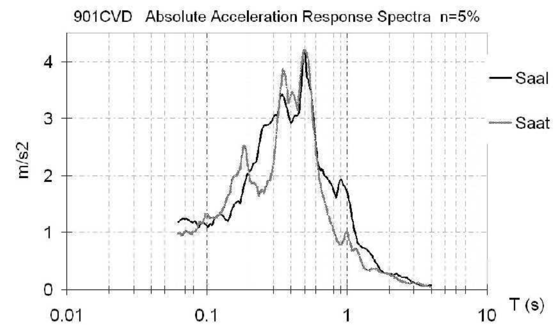
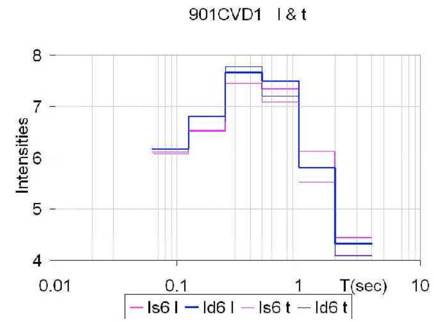
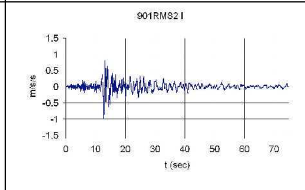
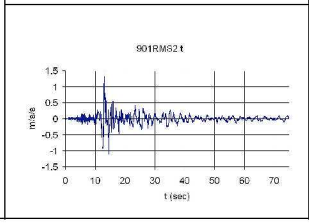
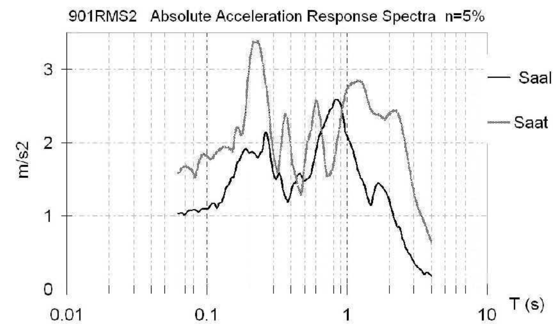
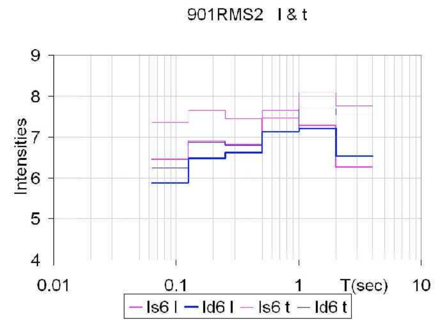
I_A: 8.43 (8.55, 8.30)</td></tr>
<tr><td>2</td><td>Source:
N. A. / Cocos Plates (Mexico)
1985.09.19

Record site:
Mex. City SCT</td><td>


</td><td>
</td><td>
</td><td>M_S: 8.1

I_S: 8.92 (8.55, 9.16)

I_A: 8.40 (8.03, 8.64)</td></tr>
</table>

3	*Source*: Romania, VSZ 1977.03.04 *Record site*: Bucharest / INCERC	 			M_{G-R}: 7.2 I_S: 8.09 (7.64, 8.37) I_A: 7.85 (7.67, 7.99)
4	*Source*: Romania, VSZ 1990.05.30 *Record site*: Cernavodă / Town Hall	 			M_{G-R}: 6.7 I_S: 6.93 (6.92, 6.93) I_A: 6.93 (6.95, 6.90)
5	*Source*: Romania, VSZ 1990.05.30 *Record site*: Rm. Sărat / Scoala	 			M_{G-R}: 6.7 I_S: 7.18 (6.70, 7.46) I_A: 6.96 (6.72, 7.13)

SUMMARY AND CONCLUSIONS

The use of instrumental data in order to evaluate the features of ground motions provides a radical increase of the accuracy and certainty and brings also information of direct interest for engineering activities that cannot be obtained otherwise.

The state of the art of the strong motion networks already has provided an impressive wealth of instrumental information and is improving at a fast pace. So, rich instrumental infomation is readily available.

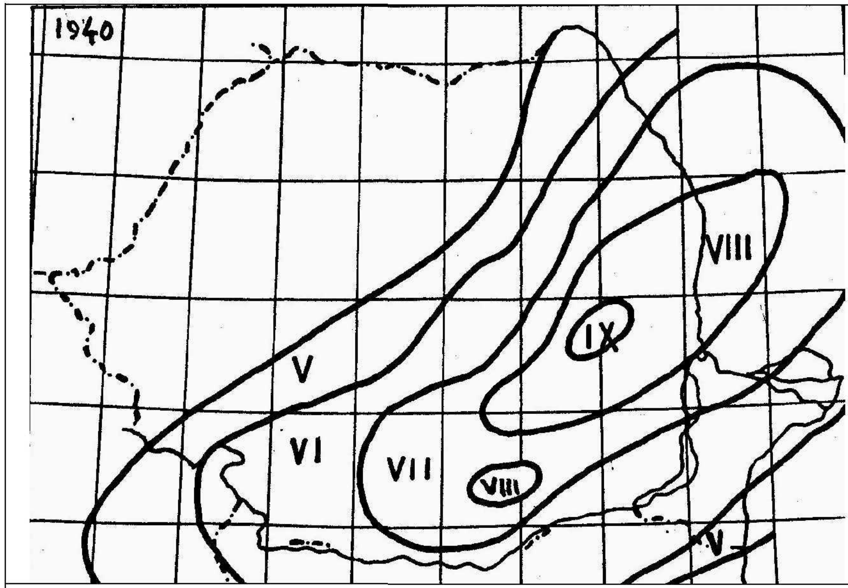
The additional information that is the most important concerns the spectral features of ground motion.

It is of highest interest to evaluate the spectral band for which macroseismic information is relevant. Otherwise, coarse errors could occur in the use of mcroseismic information (see next Section).

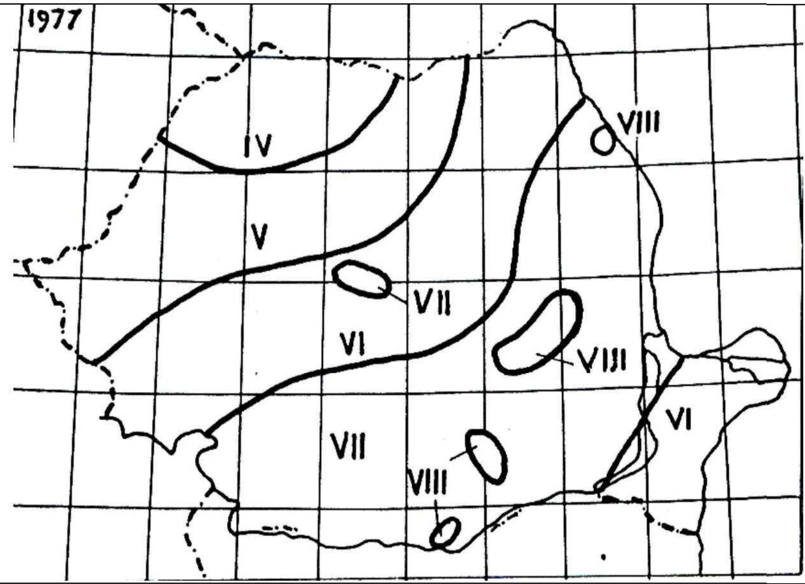
A challenge for the consideration of „historical" information: to evaluate the spectral band for which it is relevant and to possibly reevaluate intenstities, keeping in view the spectral features that can be assessed at present for ground motions at the sites dealt wth.

5. WHY MACROSEISMIC SURVEYS PERFORMED ACCORDING TO TRADITIONAL TECHNIQUES LED TO ERRONEOUS ZONATION IN ROMANIA. A CASE STUDY.

The territory of Romania was subjected during the twentieth century to two destructive earthquakes, on 1940.11.10 (M_{GR} = 7.4) and on 1977.03.04 (M_{GR} = 7.2) respectively. [Radu & al.,1990], [Sandi & al., 2002]. Isoseismal maps derived:



Vrancea earthquake of 1940.11.10



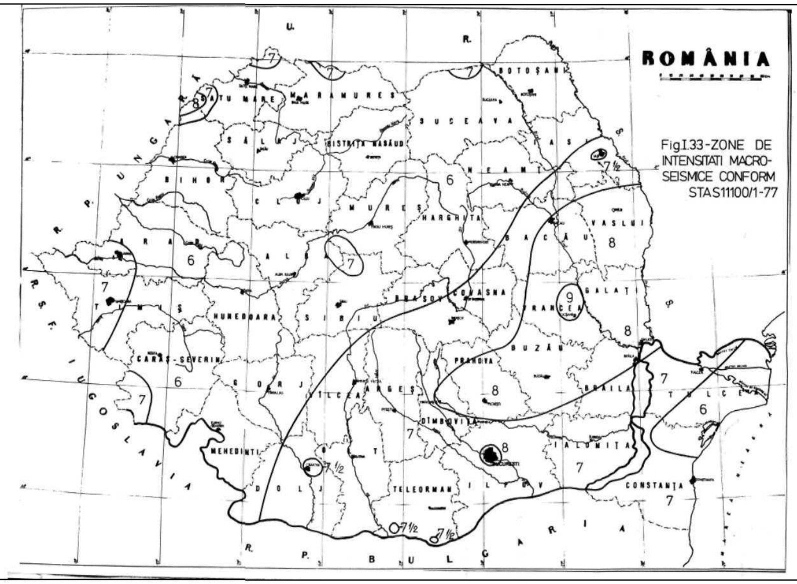
Vrancea earthquake of 1977.03.04

Remarks [Sandi & Borcia, 2010]:

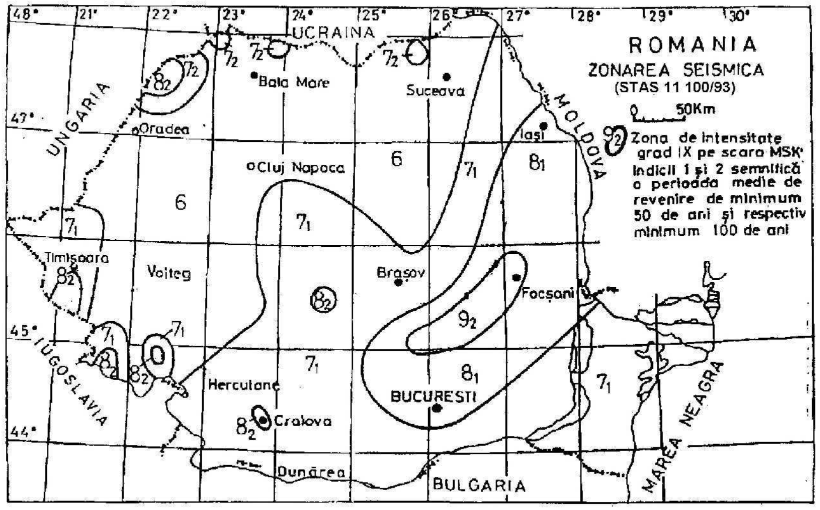
- in both cases, Bucharest pertained to an island of intensity VIII, while its surroundings pertained to a sea of intensity VII;

- that happened in spite of lack of evidence of significant geological differences between Bucharest and its surroundings.

Consequence: the official zonation map valid from 1977 to 1990 presented such an island for Bucharest. The map was modified after 1991, due to subsequent instrumental data.

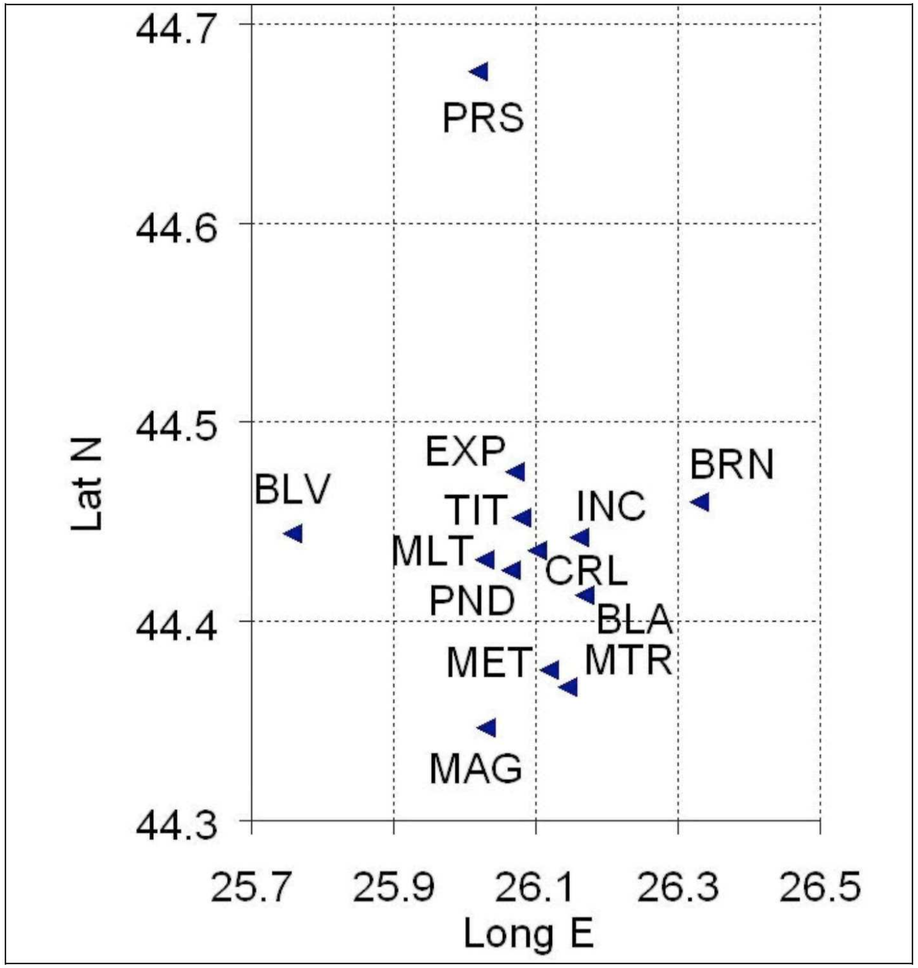


Zonation map, STAS 11700/1-77

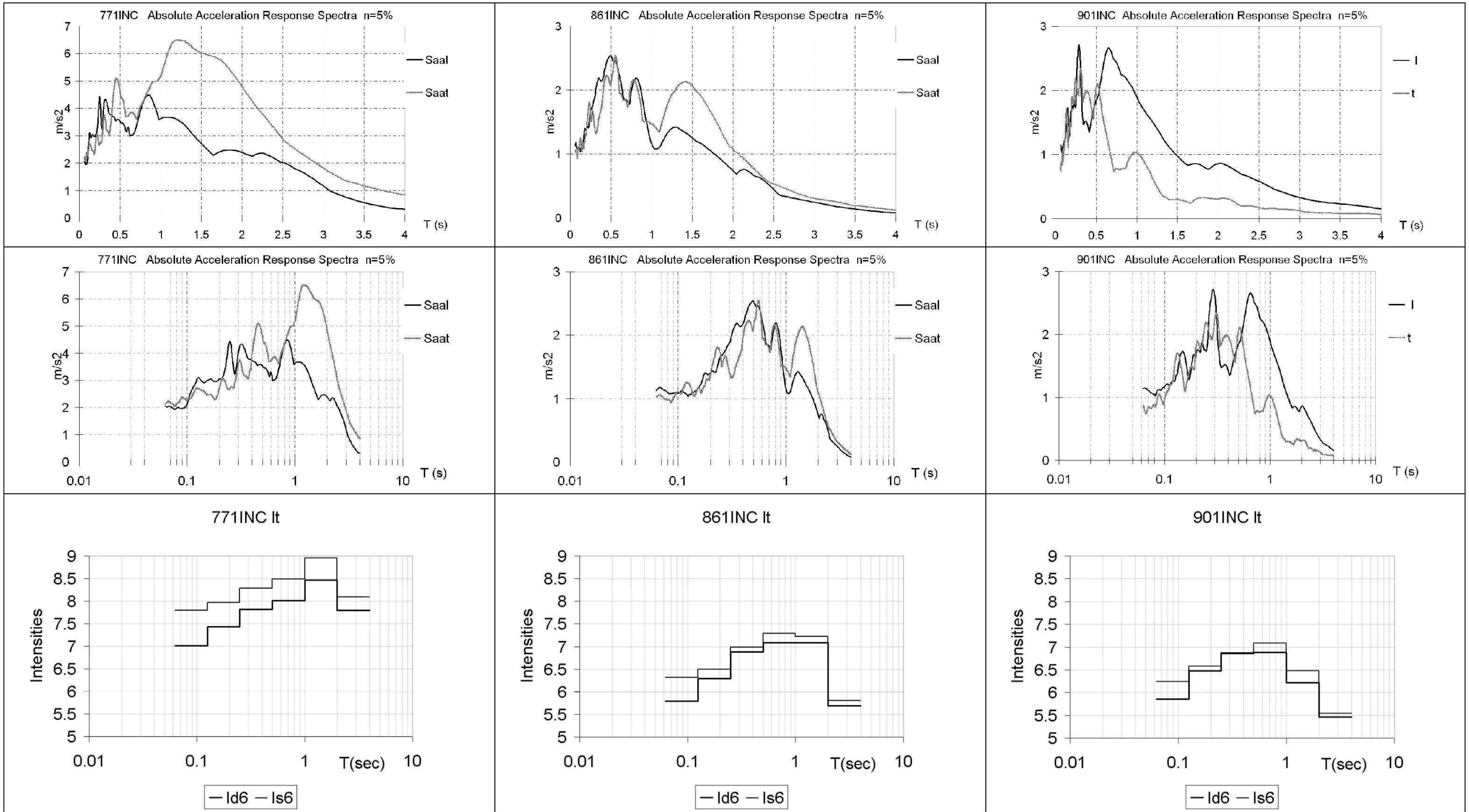


Zonation map, SR 11700/1-93

Reason of modification: the system of records of 1986 and 1990, and of response spectra computed on this basis.

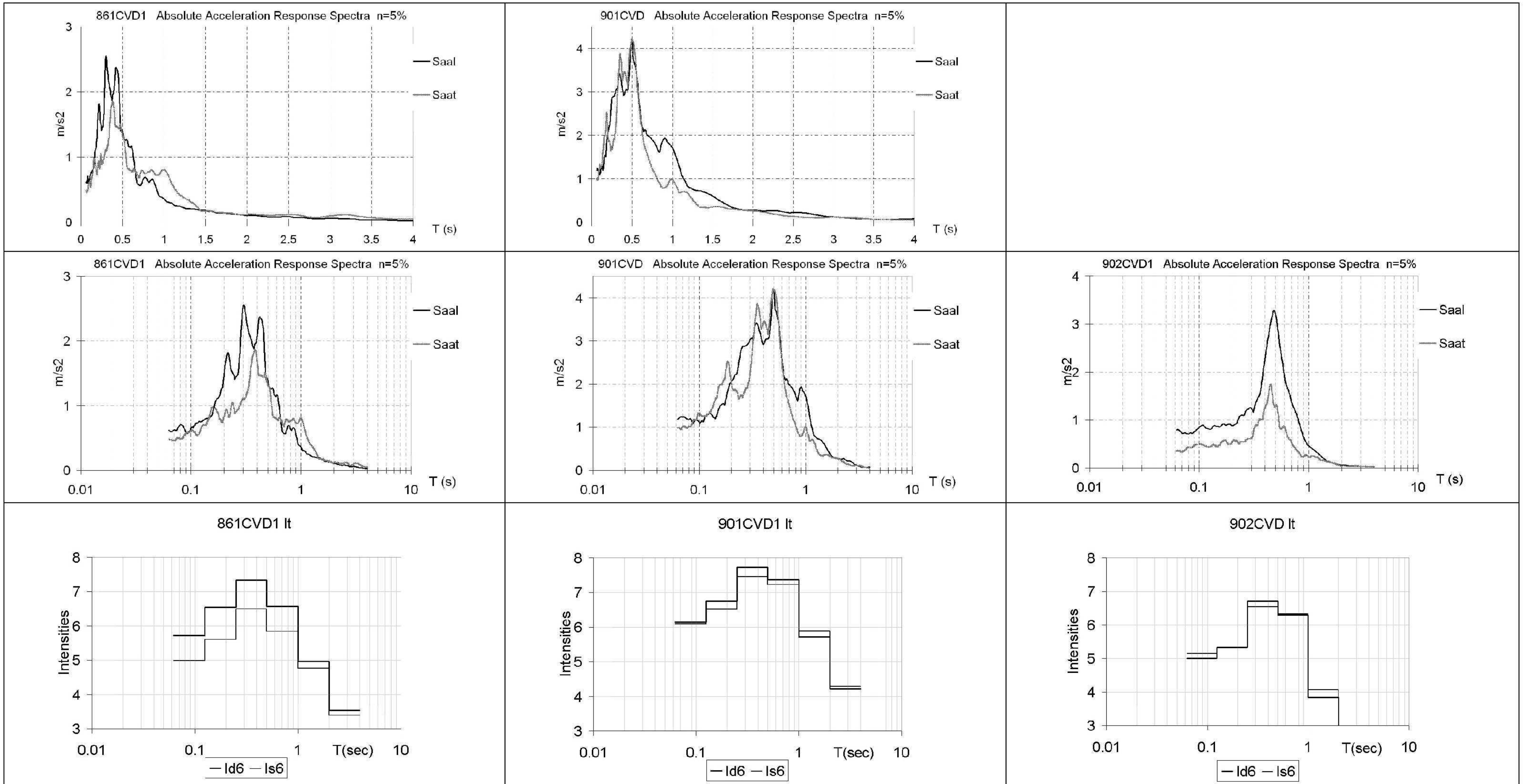


Analogical accelerographic network of Bucharest and surroundings



1977.03.04 (M_{GR} = 7.2)	1986.08.30 (M_{GR} = 7.0)	1990.05.30 (M_{GR} = 6.7)

Response spectra and averaged intensity spectra $i_s^{\sim}(\varphi', \varphi'')$ (Is6) and $i_d^{\sim}(\varphi', \varphi'')$ (Id6), for 6 dB intervals, for the sequence of records obtained at Bucharest – INCERC on 1977.03.04, 1986.08.30 and 1990.05.30



1986.08.30 (M_{GR} = 7.0)	1990.05.30 (M_{GR} = 6.7)	1990.05.31 (M_{GR} = 6.1)

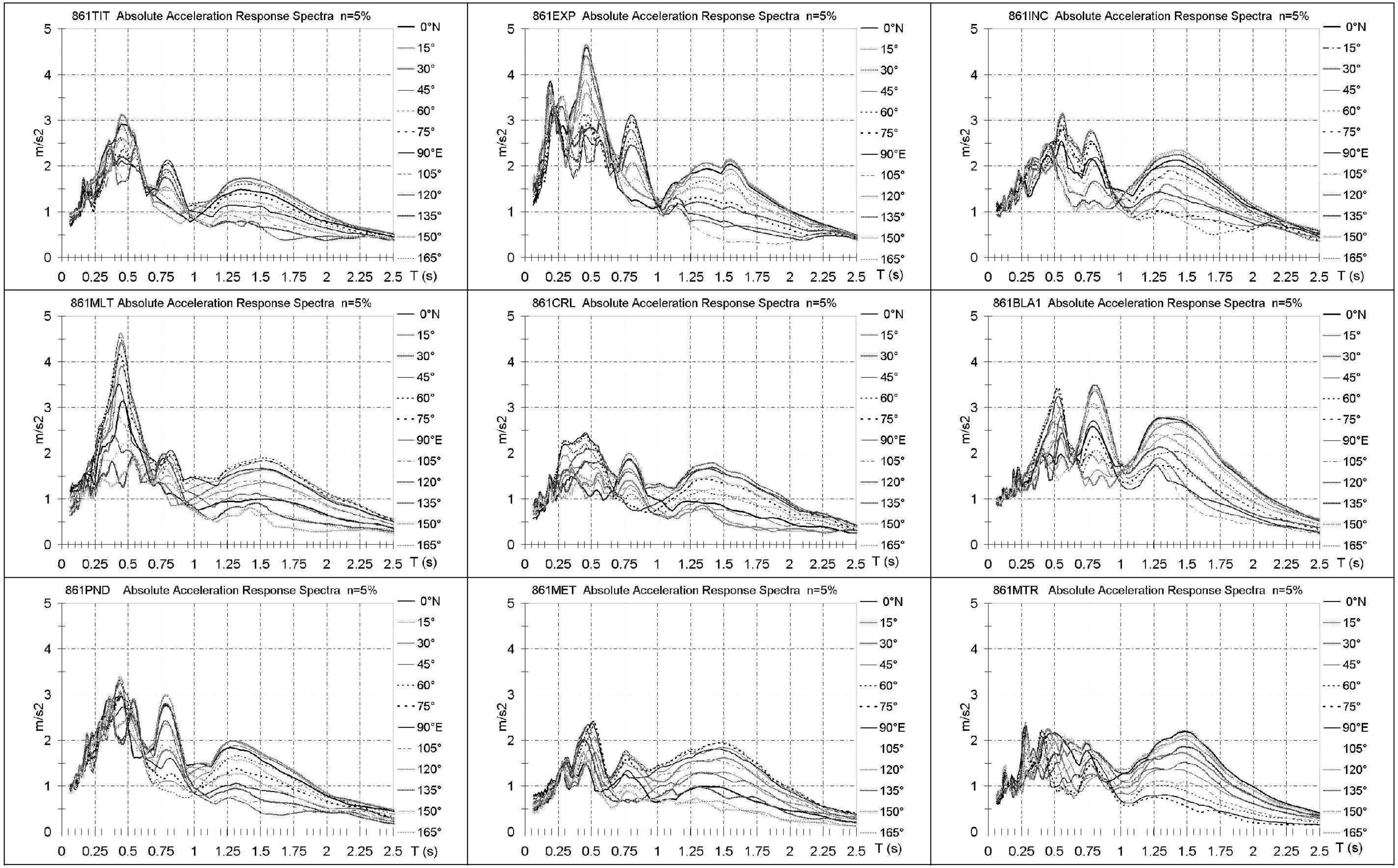
Response spectra and averaged intensity spectra $i_s^{\sim}(\varphi', \varphi'')$ (Is6) and $i_d^{\sim}(\varphi', \varphi'')$ (Id6), for 6 dB intervals, for the sequence of records obtained at Cernavodă – City Hall on 1986.08.30, 1990.05.30 and 1990.05.31

Position of response spectra (in following graphic tables)
for stations located inside Bucharest

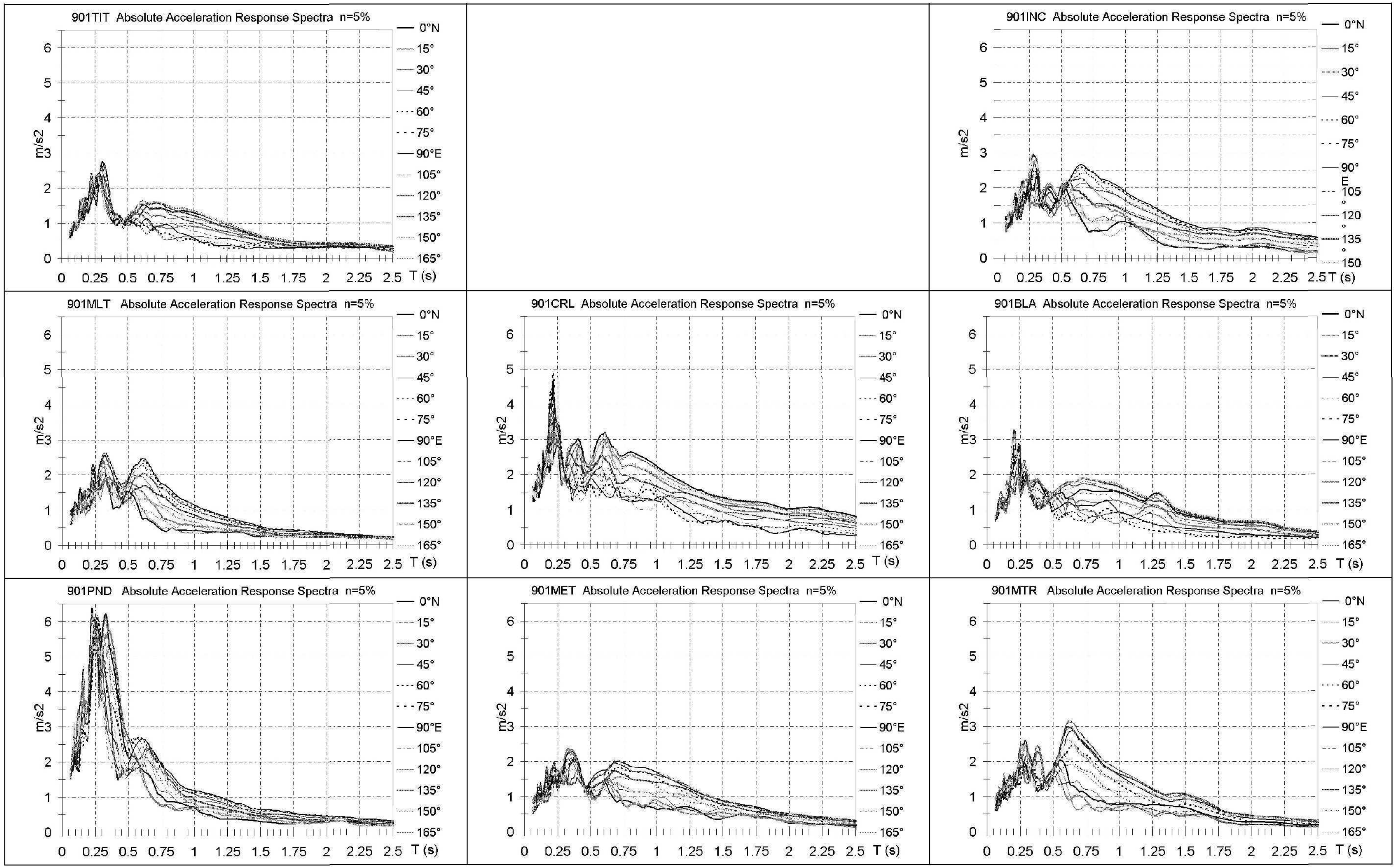
TIT – Titulescu	EXP – ROMEXPO	INC – INCERC
MLT – Militari	CRL – Carlton	BLA – Balta Albă
PND – Panduri	MET - Metalurgiei	MTR – Metro Berceni

Position of response spectra (in following graphic tables)
for stations located inside and around Bucharest

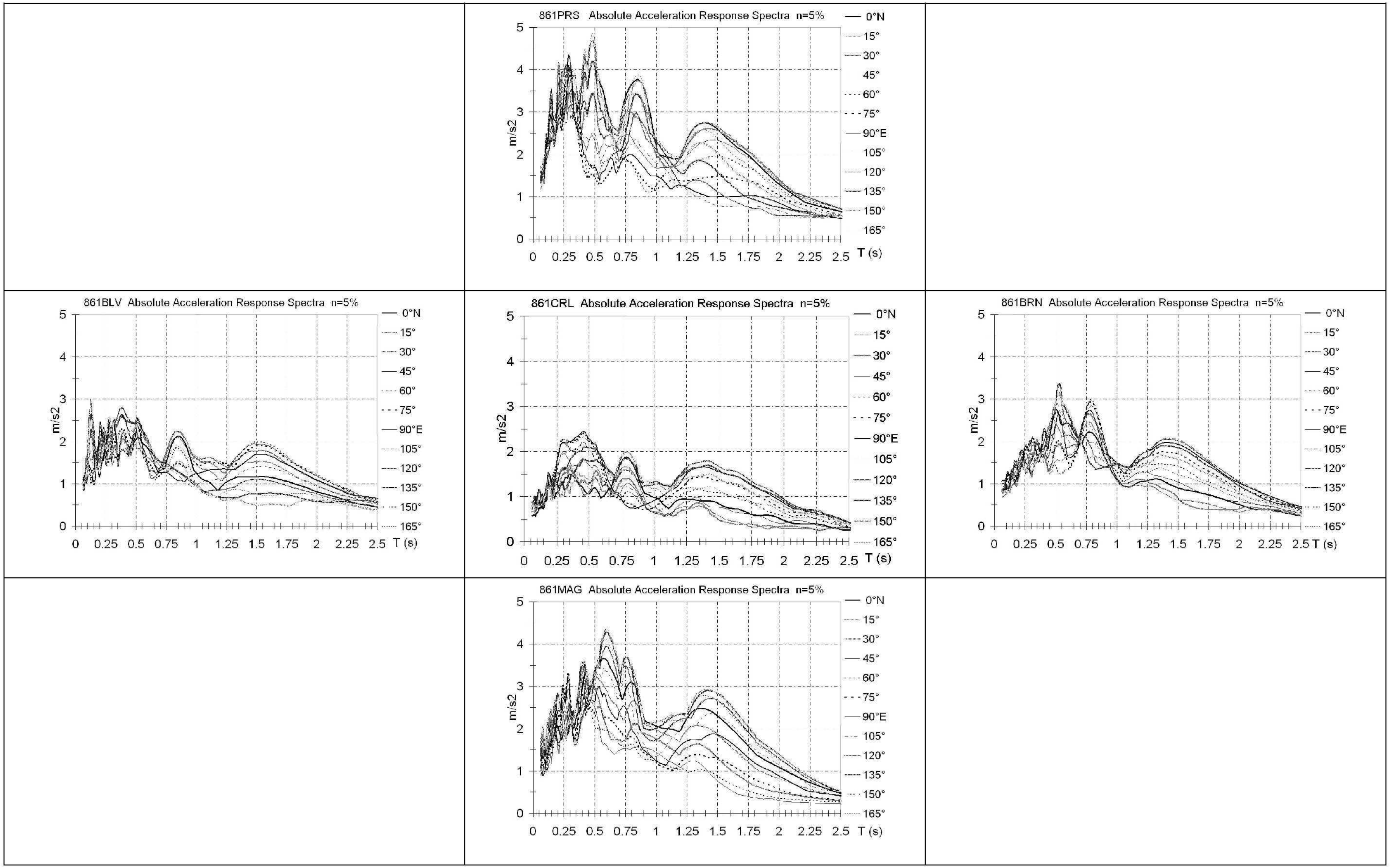
	PRS – Periş (N of city)	
BLV – Bol. Vale (W of city)	CRL – Carlton (inside)	BRN - Brăneşti (E of city)
	MAG–Măgurele (S of city)	



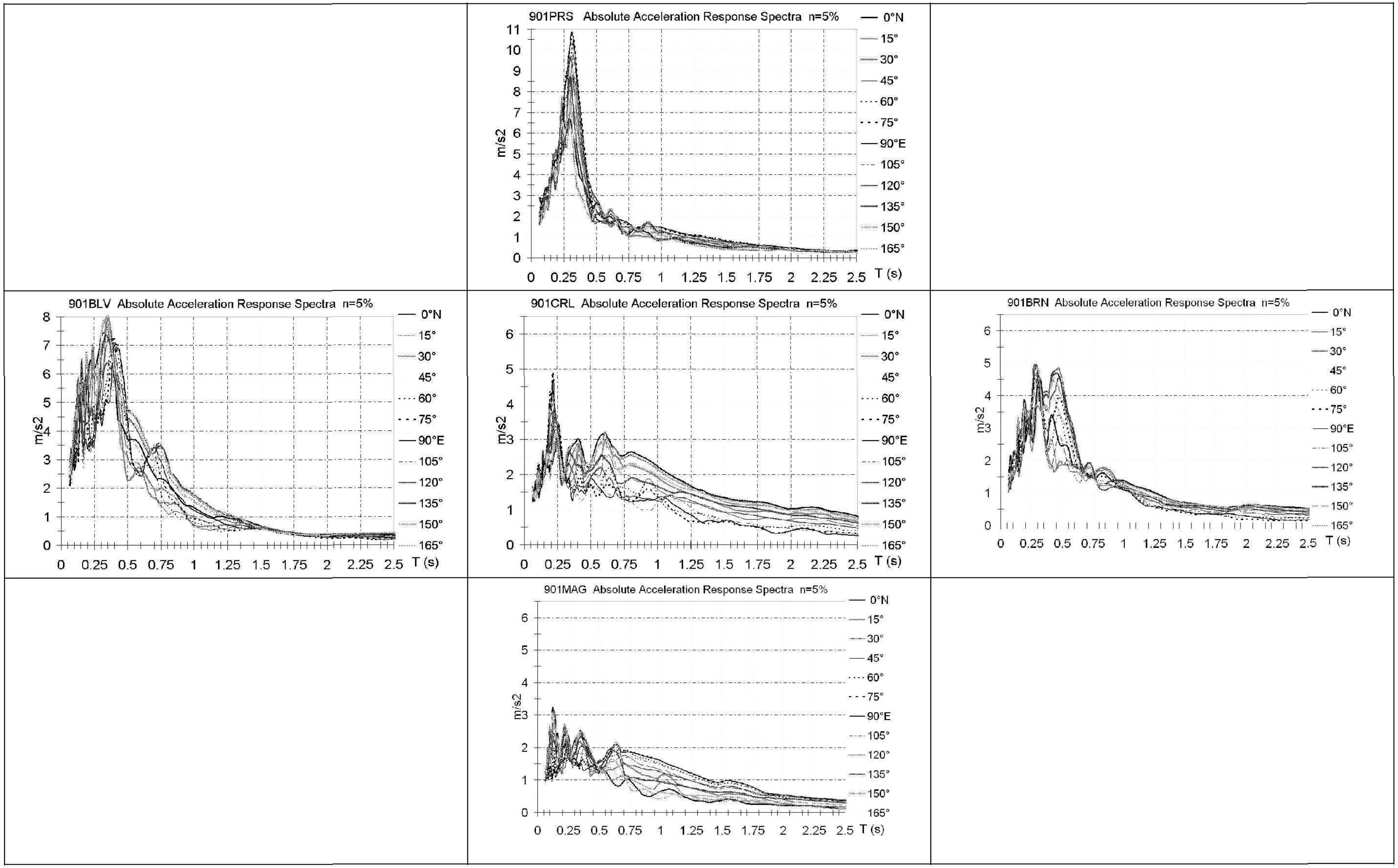
Response spectra for 12 azimuthally equidistant directions,
for stations located inside Bucharest, for the event of 1986.08.30



Response spectra for 12 azimuthally equidistant directions,
for stations located inside Bucharest, for the event of 1990.05.30



Response spectra for 12 azimuthally equidistant directions,
for stations located inside and outside Bucharest, for the event of 1986.08.30



Response spectra for 12 azimuthally equidistant directions,
for stations located inside and outside Bucharest, for the event of 1990.05.30

SUMMARY AND CONCLUSIONS

The erroneous aspects of seismic zonation referred to, which wee also in disagreement with information of geological nature, *were due to a correct use of a wrong rule*.

The processing and interpretation of instrumental information made it possible to correct the wrong conclusions of the use of traditional macroseismic assessing techniques.

The lesson provided by this case raises strong arguments in favour of an improvement of post-earthquake survey techniques. Field inspection forms should require in future also information that makes it possible to assess the spectral band for which the information obtained is relevant.

6. FINAL CONSIDERATIONS

Paying attention to the requirements of engineering activties would be most beneficial for seismologists too.

The fact that keeping the traditional view on seismic intensity is outdated deserves to be widely recognized and corresponding reaction of groups interested in this field is due.

The possibilities of passing from a mono-dimensional characterization of random variability of features of seismic ground motion to a multi-dimensional characterization deserve to be explored too. Progress in this field could contribute to a decrease of uncertainties that affect the forecasting of ground motion features, leading ultimately to improved risk control.

Setting up of a framework for joint efforts iinn this field of seismologists and engineers (e.g. for Europe: a *Joint Working Group* under the auspices of ESC and EAEE) appears to be an important need at present.

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