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ANALYSIS OF ACCELEROGRAPHIC RECORDS OBTAINED IN JASSY DURING THE 1986 AND 1990 VRANCEA EARTHQUAKES

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The interpretation, using methodological elements developed in INCERC, of data of instrumental nature obtained in Jassy during the 1986 and 1990 Vrancea earthquakes, is the main goal of the paper. The response spectra (for 12 azimuthally equidistant horizontal directions) of strong motion records, the global parameters which characterize an individual (horizontal) component of a record (effective peak values and corner (control) periods), and the instrumental intensity (global and averaged upon a frequency interval, based on destructiveness spectrum and on response spectrum) are the main numerical results obtained for the seismic records at hand. Finally, an evaluation of results, as well as conclusions useful for the aseismic design of buildings in Jassy, is presented.

1. Introduction

Numerous accelerographic records were obtained in Romania during the strong Vrancea earthquakes of 1986, August 30 ($M_{GR}=7.0$), 1990, May 30 ($M_{GR}=6.7$) and 1990, May 31 ($M_{GR}=6.1$). M_{GR} denotes here Gutenberg – Richter magnitudes. It may be noted that the Vrancea seismogenic zone is by far the most important source zone of Romania. According to [1] it releases, in the average, more than 95% of the seismic energy released per century in Romania. The wealth of instrumental information referred to made it possible to obtain a comprehensive picture on the features of Vrancea earthquakes.

In order to get a deeper insight into the features of ground motion, response spectra for 12 azimuthally different, equidistant, directions, and instrumental intensity spectra according to techniques presented in [2] and [3] were determined, for various events and sites.

The sequences of spectra for various recording stations and events put to evidence cases of tendency to stability of the dominant frequencies [4] (*e.g.*, Cernavodă Town Hall, as well as stations of Southern Moldova, sites characterized by the presence of a strong contrast of S-wave velocities at small depth), as well as cases of tendency to strong variability of the dominant frequencies (*e.g.*, stations of Bucharest, Focşani, Rm. Sărat, sites characterized by deep relatively soft ground).

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Table 1
Recording Station in Jassy Referred to in the Paper

Nr. crt.	Recording station (belonging to)	Lat. Nord	Long. Est	Symbol	1986 Aug. 30	1990 May 30	1990 May 31
1.	Jassy–Bahlui – (INCERC)	47.169	27.576	IAS1		*	*
2.	Jassy–Center – (INCERC)	47.160	27.570	IAS2	*	*	*
3.	Jassy – (NIEP)	47.193	27.562	IAS3	*	*	*

NIEP: National Institute for Earth Physics, Romania.

Table 2
Characteristics of Vrancea Earthquakes Referred to in the Paper

No	Earthquake	Lat. N	Long. E	Code Earthq	h, [km]	Date	Mw
1	Vrancea $M_{GR}=7.0$	45.53	26.47	861	133	1986, Aug. 30	7.3
2	Vrancea $M_{GR}=6.7$	45.82	26.90	901	91	1990, May 30	7.0
3	Vrancea $M_{GR}=6.1$	45.83	26.89	902	79	1990, May 31	6.4

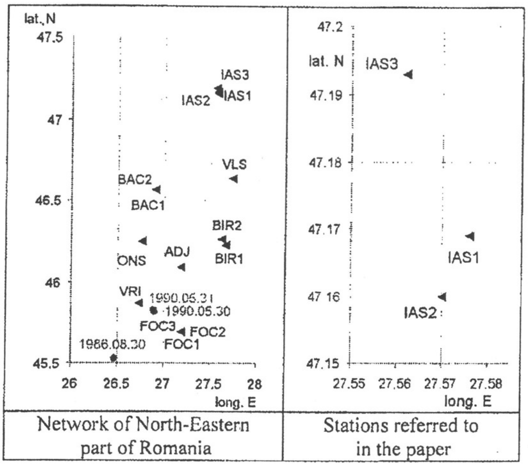

Fig. 1.– Map of instrumental epicenters and of recording stations in North-Eastern part of Romania.

2. Methodological Aspects

The investigation of the features of ground motion and of the reasons of these features as well, as related to the object of the paper, was performed using following main approaches:

a) determination of response spectra for strong motion records for 12 horizontal, azimuthally equidistant, directions, as presented in [5];

b) calculation of corner periods of response spectra;

c) determination of intensity spectra, as defined in [3] and used in [5].

Following definitions are used for global intensities, for frequency dependent intensities and for intensities averaged upon spectral bands:

1. For global intensities.

1.1. The global intensity based on response spectra, I_S:

a) the parameters

(1) $$\text{EPAM} = \frac{\max_T s_{aa}(T, 0.05)}{2.5}$$

and

(2) $$\text{EPVM}, [\text{m/s}] = \frac{\max_T s_{av}(T, 0.05)}{2.5},$$

are introduced, where: $s_{aa}(T, n)$ is the response spectrum of absolute accelerations, related to periods, [m/s^2], $s_{av}(T, n)$ – the response spectrum of absolute velocities, related to periods, [m/s], $s_{rv}(T, n)$ – the response spectrum of relative velocities, related to periods, [m/s], and $s_{rd}(T, n)$ – the response spectrum of relative displacements, related to periods, [m];

b) the intensity, I_S, is given by the expression

(3) $$I_S = \log_4(\text{EPAM} \times \text{EPVM}) + 8.0.$$

1.2. The Arias intensity, I_A, is given by the expression

(4) $$I_A = \log_4 \int [w_g(t)]^2 \, \mathrm{d}t + 6.75.$$

2. For intensities depending on frequencies, *varepsilon*, [Hz].

2.1. The intensity based on response spectra:

(5) $$i_s(\varphi) = \log_4[s_{aa}(\varphi, 0.05) s_{va}(\varphi, 0.05)] + 7.70.$$

2.2. The intensity based on destructiveness spectrum:

(6) $$i_d(\varphi) = \log_4 \left[\int w_a^2(t, \varphi, 0.05) \, \mathrm{d}t \right] + 5.75,$$

where the (absolute) accelerogram, $w_a(t, \varphi, 0.05)$, for a pendulum of (undamped) natural frequency, φ, and 5% fraction of critical damping is used.

3. For intensities averaged upon spectral bands the rule of averaging upon a frequency band (φ', φ'').

3.1. For the spectrum based intensity:

(7) $$i_s(\varphi', \varphi'') = \log_4 \left[\frac{1}{\ln(\varphi', \varphi'')} \int \frac{1}{\varphi} s_{aa}(\varphi, 0.05) s_{va}(\varphi, 0.05) \, \mathrm{d}\varphi \right] + 7.70.$$

3.2. For the intensity based on destructiveness spectrum:

(8) $$i_d(\varphi', \varphi'') = \log_4 \left\{ \frac{1}{\ln(\varphi', \varphi'')} \int \frac{1}{\varphi} \left[\int w_a^2(t, \varphi, 0.05) \, \mathrm{d}t \right] \mathrm{d}\varphi \right\} + 5.75.$$

The definitions adopted for effective peak values [6] are

(9) $$\mathrm{EPA} = \frac{(s_{aa\,\mathrm{aver.\,on\,0.4}s})\max}{2.5},$$

(10) $$\mathrm{EPV} = \frac{(s_{rv\,\mathrm{aver.\,on\,0.4}s})\max}{2.5},$$

(11) $$\mathrm{EPD} = \frac{(s_{rd\,\mathrm{aver.\,on\,0.4}s})\max}{2.5},$$

and for the corner (control) periods

(12) $$T_C = 2\pi\frac{\mathrm{EPV}}{\mathrm{EPA}},$$ (13) $$T_D = 2\pi\frac{\mathrm{EPD}}{\mathrm{EPV}},$$

where s_{aa}, s_{rv}, s_{rd} represent the response spectra for absolute accelerations, relative velocities and relative displacements, respecively, depending on frequency, φ, or period, T, and for 5% fraction of critical damping.

3. 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 [2]. This was done for 5% critical damping. The availability of response spectra along 12 equidistant directions 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.

The values of corner periods, T_c, in Table 3, are ranged between 0.37 s and 0.76 s, making acceptable the value 0.7 s for T_c in β-curves corresponding to the code P 100-1/2006 [6] for Jassy.

Table 3 reports a very good correlation between values of Arias intensity, I_A, and values of intensity, based on destructivness spectrum, averaged over the frequency interval (0.25 Hz, 16.0 Hz), I_{D1}.

The examination of the sequences of spectra in Fig. 2 makes it possible to emphasize the fact that, for stations IAS2 and IAS3, while the dominant periods were around 0.4 s in 1986, they become relatively short in 1990 when the period spectral peaks of more than 0.25 s got a secondary importance; in almost all response spectra there are present peaks at around 0.75 s.

Table 3
Global Characteristics of Horizontal Components of Records Obtained in Jassy

No	Code earthq.	Code station	Code axis	pga	pgv	pgd	epa	epv	epd	T_c	I_s	I_{s1}	I_A	I_{D1}
1	861	IAS2	l: NS	0.641	0.0604	0.0089	0.524	0.0483	0.0091	0.58	5.7	5.8	5.4	5.3
2	861	IAS2	t: EW	1.464	0.1175	0.0144	1.475	0.1146	0.0122	0.49	7.1	7.0	6.4	6.2
3	861	IAS3	l: NS	0.669	0.0742	0.0130	0.633	0.0606	0.0187	0.60	6.0	5.9	6.3	6.3
4	861	IAS3	t: EW	0.996	0.0792	0.0127	0.876	0.0757	0.0155	0.54	6.3	6.2	6.4	6.5
5	901	IAS1	l: N150E	1.356	0.0601	0.0088	0.913	0.0496	0.0122	0.34	6.6	6.4	6.8	6.7
6	901	IAS1	t: N60E	0.900	0.0679	0.0089	1.065	0.0637	0.0117	0.38	6.6	6.5	6.7	6.7
7	901	IAS2	l: NS	1.262	0.0513	0.0072	0.762	0.0579	0.0090	0.48	6.3	6.2	6.3	6.3
8	901	IAS2	t: EW	1.095	0.0569	0.0129	0.842	0.0499	0.0150	0.37	6.2	6.3	6.6	6.5
9	901	IAS3	l: NS	0.988	0.0742	0.0152	0.824	0.0798	0.0128	0.61	6.7	6.3	6.7	6.7
10	901	IAS3	t: EW	1.064	0.0647	0.0152	0.805	0.0526	0.0130	0.41	6.5	6.1	6.7	6.7
11	902	IAS1	l: N150E	0.760	0.0414	0.0061	0.547	0.0361	0.0083	0.41	5.8	5.7	5.7	5.7
12	902	IAS1	t: N60E	0.312	0.0198	0.0035	0.351	0.0230	0.0052	0.41	4.9	5.0	5.0	5.0
13	902	IAS2	l: NS	0.368	0.0220	0.0038	0.290	0.0201	0.0067	0.44	4.8	4.8	4.7	4.7
14	902	IAS2	t: EW	0.458	0.0367	0.0061	0.332	0.0404	0.0063	0.76	5.6	5.3	5.2	5.2
15	902	IAS3	l: NS	0.496	0.0295	0.0070	0.485	0.0290	0.0069	0.37	5.6	5.3	5.6	5.6
16	902	IAS3	t: EW	0.529	0.0397	0.0076	0.446	0.0449	0.0073	0.63	5.6	5.4	5.6	5.6

N o t e: indices used: l – (longitudinal): first horizontal direction of record; t – (transversal): second horizontal (orthogonal with the first one) direction of record; lt – averaging upon two orthogonal horizontal directions; 1 – (one): averaging of frequency dependent intensities over the frequency interval (0.25 Hz, 16.0 Hz); – – (no index): global intensities.

Units used for kinematic parameters: m, m/s, m/s^2.

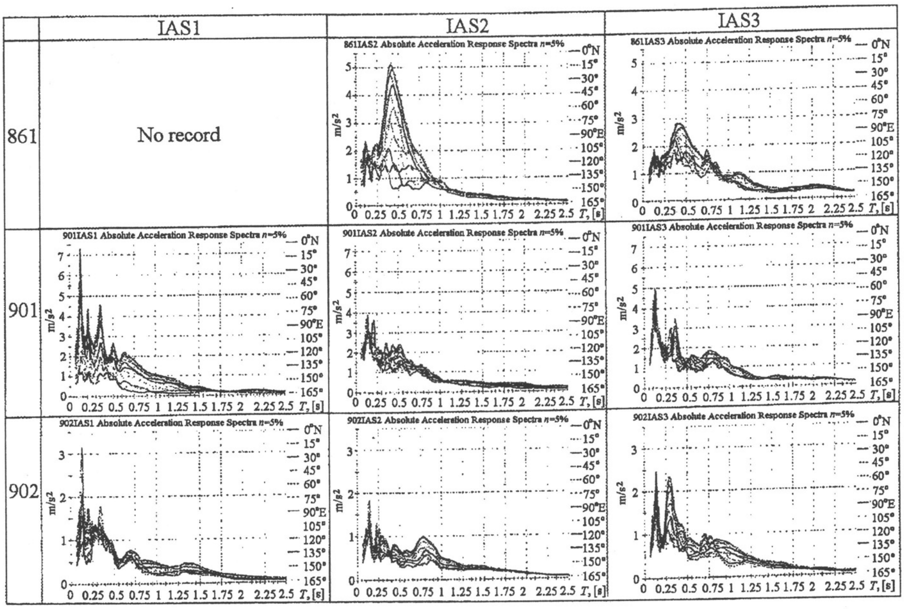

Fig. 2.– Response spectra for absolute accelerations, along 12 equidistant azimuthal directions, for records obtained in Jassy.

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. 2 for IAS2 station, for 1986 seismic event).

In Fig. 3 are presented the results of statistics (median and median +/− one standard deviation) over normalized acceleration response spectra, for each record station in Jassy (left) anf for each seismic event (right). These results confirm the value $T_C = 0.7$ s. adopted in [6] for Jassy.

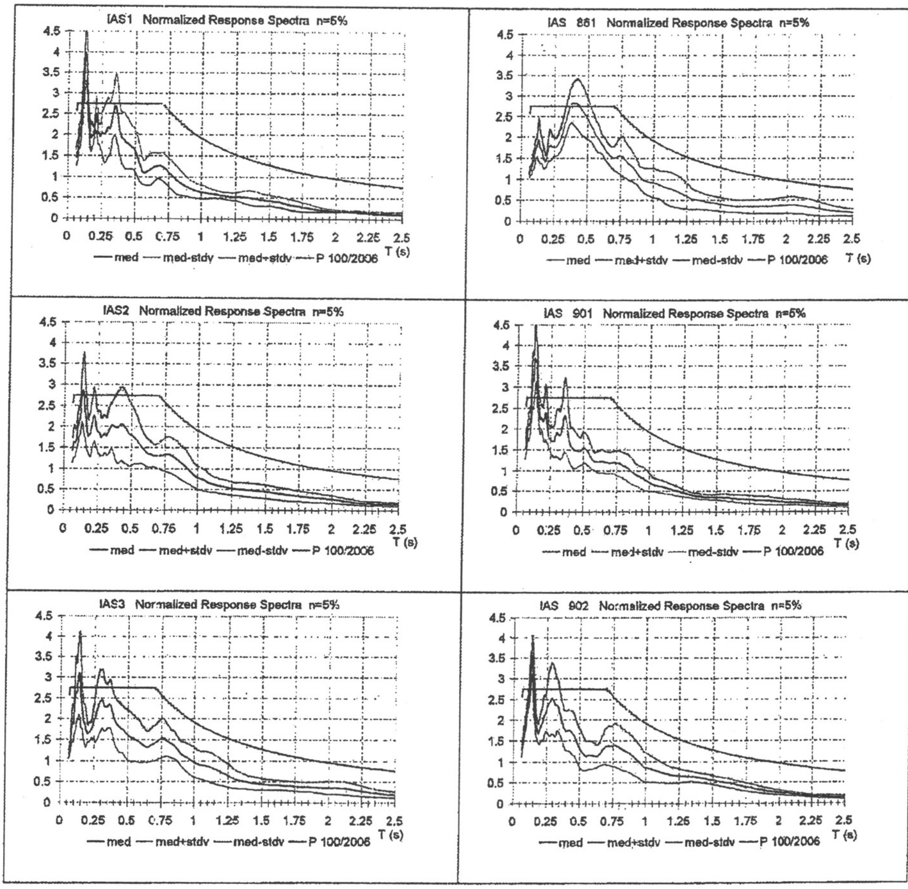

Fig. 3.– Statistics over normalized acceleration response spectra and β-curves corresponding to the code P 100-1/2006 [6] for Jassy.

4. Intensity Spectra Derived on the Basis of Accelerographic Records

The intensity spectra presented subsequently were derived on the basis of accelerographic records. The intensity spectra are organized as follows: a) the abscissa corresponds to lg$T$; b) the ordinate corresponds to (instrumental) intensity values.

In the same way as that put to evidence by the response spectra of Fig. 2, the intensity spectra presented in Fig. 4 illustrate the evolution of global intensity of ground motion, as well as the shift of most severe intensities from one event to the other.

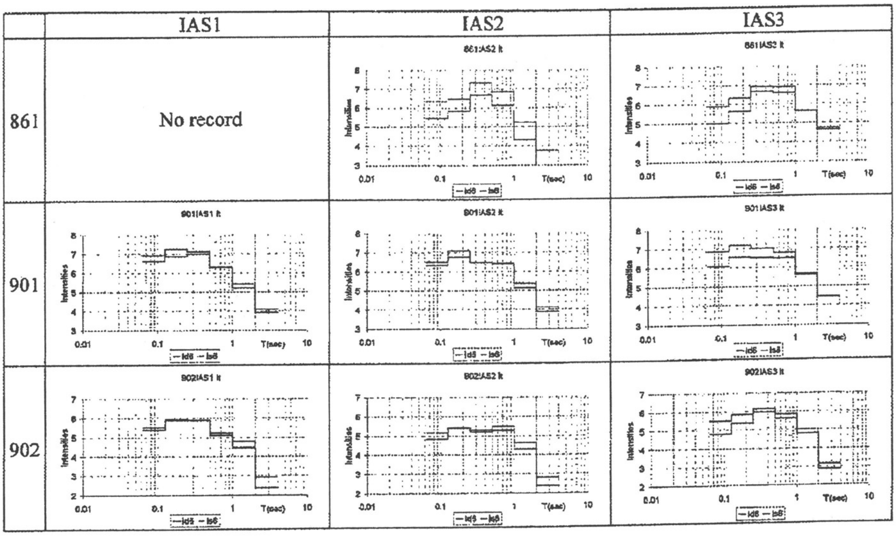

Fig. 4.– Averaged intensity spectra $i_s^{\sim}(\varphi', \varphi'')$ and $i_d^{\sim}(\varphi', \varphi'')$, for 6 dB intervals, for Jassy.

5. Final Considerations

A look at the features of strong motion records at hand and of spectra determined showed that it is particularly important to consider the whole of data at hand, also for Jassy. It turned out that the isolated consideration of one station or even of one event as a whole could lead to non-realistic conclusions. This is why the availability of strong motion data for several events originating in the same source zone is so important.

An aspect of primary interest for this paper is represented by the fact that for sites IAS2 and IAS3 there was a strong tendency to variability of spectral contents of ground motion (as illustrated by the response spectra of Fig. 2). 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.

The examination of Fig. 4 makes it possible to formulate some comments, provided the use of definitions of the averaged intensities, $i_s^{\sim}(\varphi', \varphi'')$ and $i_d^{\sim}(\varphi', \varphi'')$, is accepted. There appears to be a significant variation, depending on period or frequency interval, of the spectral band related averaged intensities. This provides a picture concerning the spectral intervals for which the intensities are higher and, consequently, the severity of seismic action appears to be higher. There are differences between the outcome of use of the alternative definitions, $i_s^{\sim}(\varphi', \varphi'')$ and $i_d^{\sim}(\varphi', \varphi'')$, but the differences are moderate and definitely lower than the possibilities of discrimination provided by the use of macroseismic intensities derived on the basis of visual post-earthquake surveys.

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ANALIZA ÎNREGISTRĂRILOR ACCELEROGRAFICE OBŢINUTE ÎN IAŞI ÎN TIMPUL CUTREMURELOR VRÂNCENE DIN 1986 ŞI 1990

(Rezumat)

Principala preocupare a autorului a fost interpretarea datelor de natură instrumentală stabilite la Iaşi în timpul cutremurelor vrâncene din 1986 şi 1990, utilizând dezvoltările metodologice obţinute la INCERC. Principalele rezultate numerice obţinute sunt: spectre de răspuns (pentru câte 12 direcţii orizontale echidistante), parametrii globali ce caracterizează o componentă (orizontală) a unei înregistrări (valori efective de vârf şi perioade de colţ (de control)) şi intensităţi seismice instrumentale (globale şi mediate pe diferite intervale de frecvenţă, bazate pe spectrul de destructivitate şi pe spectrul de răspuns). În final sunt prezentate evaluarea rezultatelor şi concluzii privind proiectarea la cutremur a construcţiilor din Iaşi.