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A VIEW TO THE INTERMEDIATE-DEPTH VRANCEA EARTHQUAKE OF MAY 30, 1990: CASE STUDY IN NE BULGARIA

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SUMMARY

A deterministic analytical procedure for ground motion modelling, combining both modal summation and mode coupling techniques has been implemented to obtain synthetic seismic signals at Russe, NE Bulgaria, due to one of the strongest Vrancea intermediate-depth earthquakes, which occurred during the last century, May 30, 1990. The frequency content of the synthetic signals in different frequency ranges, up to 1 and 2Hz, has been studied separately. The results of this study, i.e. time histories and related ground motions parameters, can be used for different earthquake engineering analyses, e.g. structural performance assessments.

INTRODUCTION

During the last century, five strong Vrancea intermediate-depth earthquakes (M>6.0) were significantly felt in Bulgaria. These earthquakes have been typical examples of far-reaching seismic effects, e.g. the quake of March 4, 1977 (Mw = 7.5) was felt at epicentral distances up to 1000 km in Central Europe, and macroseismic intensities I > VIII (MSK-64) in Romania, I = VII - VIII at Russe, Bulgaria, I = V at Zagreb, Croatia and I = IV at Budapest (Hungary), were reported [1,2]. The Vrancea seismic record and the recent deterministic seismic hazard estimates [3] show that the seismic hazard in Romania and NE Bulgaria is mainly controlled by the large Vrancea intermediate-depth earthquakes. Due to these earthquakes, macroseismic intensity I = IV – VIII (MSK-64, epicentral distances 210-250km) has been reported at Russe, one of the main Bulgarian cities, fig. 1. Due to the last strong earthquake of May 30, 1990 (M_w = 6.9) a maximum ground acceleration of 114.62 cm/s^2 was registered at Russe. Some of the damages on masonry structures in NE Bulgaria, due this strong event, documented at similar epicentral distances, but at different azimuths are shown in fig. 2.

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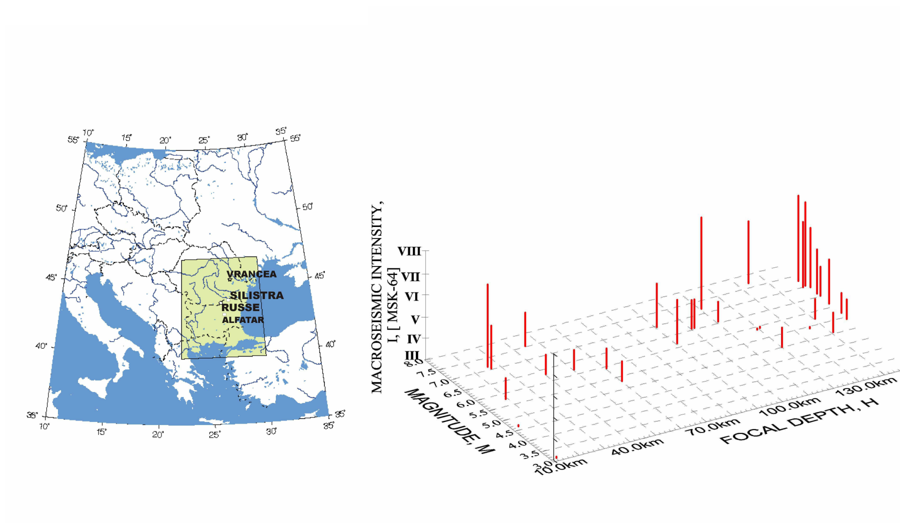

Date	M	I, MSK	H, km
23.01.1838	6.9	VII	150
17.08.1893	6.1	IV - V	100
10.09.1893	6.1	IV - V	100
31.08.1894	6.5	IV - V	150
08.06.1903	5.4	IV	150
13.09.1903	6.2	IV	50
06.02.1904	5.9	IV	60
06.10.1908	6.8	VI	150
25.05.1912	6.3	IV	40
26.10.1914	5	IV	120
01.11.1929	6.6	V	150
29.03.1934	6.9	V	150
13.07.1938	5.7	IV	150
24.06.1940	5.8	III	120
22.10.1940	6.2	V	150
13.11.1940	7.3	VII	150
07.09.1945	6.5	IV	100
09.10.1945	6.2	V	90
17.05.1953	5	IV	140
13.04.1954	4.9	III	120
01.05.1955	5.4	III	135
31.05.1959	4.7	III - IV	20
04.01.1960	5.3	IV	60
14.01.1963	5.9	III	118
17.07.1974	5.7	IV	140
04.03.1977	7.2	VII - VIII	110
30.08.1986	7.2	VI	133
30.05.1990	6.9	V	90

Figure 1. Left: Schematic location of Vrancea Seismic zone and Russe, Silistra and Alfatar towns. Right: Macroseismic intensity reported at Russe due to Vrancea intermediate-depth earthquakes, plotted versus earthquakes' focal depth and magnitude [4].

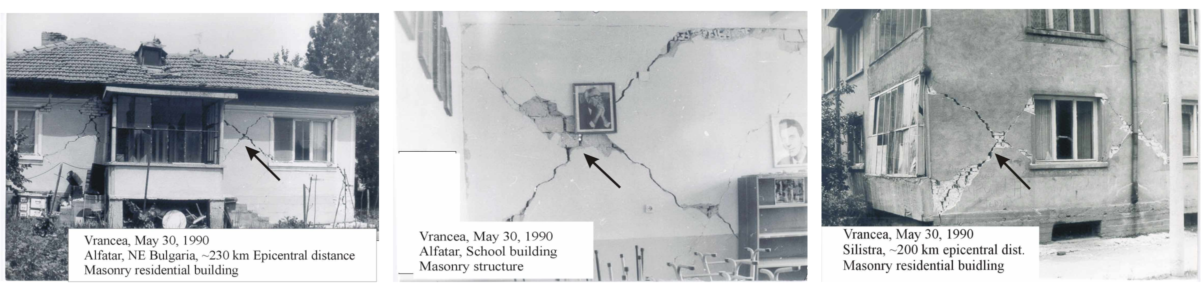

Figure 2. Some damages in NE Bulgaria, due to the Vrancea Earthquake of May 30, 1990. The schematic location of the towns mentioned in fig.2 is shown in fig. 1, left.

Accelerograms due to the Vrancea intermediate-depth earthquakes have been recorded by the seismic networks of Romania, the Academy of Science from Moldova, and the Bulgarian Academy of Sciences. Waveforms (recorded accelerograms) in Romania and Bulgaria, due to the Vrancea earthquakes, are available through the existing strong motion databases [5, 6]. Recent detailed analysis of the Bulgarian data applying the moving windows technique, a new data processing technique in the frequency – time domain, and tables with the main characteristics of the recorded accelerograms was provided by Paskaleva [7]. The control periods, T_c, of the response spectra extracted from the available Bulgarian records are T_c = 0.4 - 1.6 s.

Maps of practical use, as design ground accelerations, maximum velocities and displacements, have been recently produced [3, 9, 10] applying an advanced deterministic procedure [11, 12] for different Vrancea earthquake scenarios. From the deterministic modelling it can be concluded that the Vrancea earthquakes can produce ground displacements in NE Bulgaria up to 30 - 60 cm, velocities up to 50 - 100 cm/s and peak accelerations over 50 % of {g}. These computed DGA values for NE Bulgaria significantly exceed the prescribed seismic loading in the BG Code'87 and the recorded PGA for VR901.

Some investigations concerning the modelling of long period ground motion and the influence of the seismic source parameters on the ground motion (frequency content up to 1Hz) due to strong intermediate-depth Vrancea earthquakes have been performed in the framework of the UNESCO-IUGS-IGCP Project 414, www.ictp.trieste.it, [4, 13, 14].

The main idea of this study is to extend the investigations to higher frequencies, of earthquake engineering interest, considering the new structural data defining the average properties of the profile Vrancea - Russe [15] as the bedrock structure. Thus the synthetic seismic load, at selected sites in the town of Russe, NE Bulgaria, due to the Vrancea earthquake of May 30 (VR901, $M_w = 6.9$, focal depth H = 74 km), has been computed applying a deterministic analytical procedure, based on modal summation and modal coupling techniques [16]. The synthetic seismic signals have been compared with available instrumentally recorded accelerations, considering separately frequencies of 1 and 2 Hz.

THE METHOD AND THE DATA

To simulate the ground motion at Russe a deterministic analytical approach, combining the modal summation technique, applied to model the seismic wave propagation between the seismic source and the site of interest [17, 18, 19], with the mode coupling approach [20, 21, 22], used to model the seismic wave propagation through the anelastic, laterally inhomogeneous, sedimentary media of the target site, was implemented. Thus theoretical acceleration, velocity and displacement time histories at the recording site at Russe were computed. A model, consisting of two horizontally layered half-spaces in welded contact, fig.3, has been adopted for these numerical experiments. It includes the bedrock structure, representative of the geological profile between the seismic source and the site of interest, and the target site structure. The detailed geological and geotechnical data available for the uppermost 100 m in Russe [24] have been used to define the uppermost part of the local model [4]. A regional structural model (bedrock model) representative of the path Vrancea-Russe, which passes through the Carpathians and the Moesian Platform, has been provided in [9]. With the progress of the UNESCO- IUGS – IGCP Project 414 new geological information about the bedrock become available [15 & personal communications] and new computations have been started both in Romania and Bulgaria. The adopted models used in these computations are shown in fig. 3. The seismic source has been modelled as a buried double couple. The data provided in [24], $M_w = 6.9$, focal depth of 74 km, strike = 236^o, dip=63 ^{o} and rake = 101 ^{o} have been used in the computations.

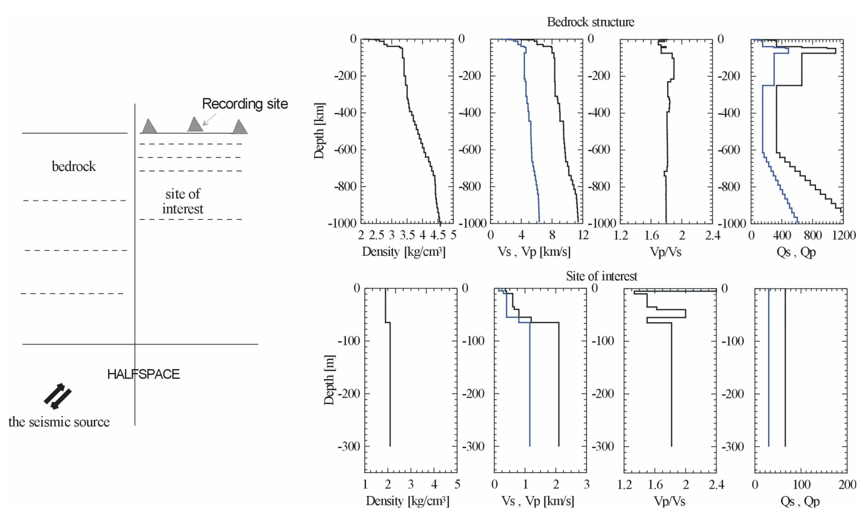

Figure 3. Structural models for the bedrock (top) by Cioflan, pp com., and for the target site (bottom) by [Paskaleva et al., 2001], which have been used for the computation of the synthetic ground motion.

DISCUSSION OF THE RESULTS

The available, instrumentally corrected, accelerograms have been rotated and low-passed filtered with cut-off frequencies of 1Hz and 2Hz. Using the available data, synthetic accelerograms, velocigrams and displacements have been computed for the transverse (TRA), radial (RAD) and vertical (VER) ground motion components. Response spectra for 5% damping and absolute energy input [26, 27] have been computed. Both synthetic and observed data have been processed using the SeismoSignal data processing package, 2.00, and peak ground acceleration, velocity and displacement' values, PGA, PGV and PGD, PGV/PGD ratio, Arias Intensity and A95 (the acceleration level below which 95% of the total Arias intensity is contained) have been computed. Comparisons between the synthetic and observed signals for frequencies up to 1Hz and 2Hz are shown in figs. 4 and 5, respectively and Table 1.

Considering the fact that no data fitting has been done and that all the data have been used as they were published in the literature, both comparisons, shown in fig. 4 and 5 respectively, can be accepted as successful and very encouraging. For the case of frequencies up to 1Hz, fig. 4 and Table 1, the best fit in terms of peak acceleration (PGA), velocity (PGV), displacement (PGD), PGV/PGD ratio, A95 and response spectra, SA 5%, has been obtained for the TRA component, (e.g. observed PGA = 14.10 against computed PGA = 13.90 cm/s^2). The origin of the time scales of synthetic and observed signals differ, since the available records were obtained by SMA - 1 analogue instrument that was not equipped by any time synchronising device. The computed TRA PGA, PGV and PGD and the energetic parameters, Arias intensity, A95, are larger than the observed ones. The synthetic TRA SA5% and the computed absolute input energy EI are larger than the observed ones almost over the whole frequency interval considered.

For both RAD and VER components all the synthetic values underestimate significantly the observed one. The best fit for these components is obtained for the PGV/PGA ratio (RAD: 0.233 computed against 0.266 observed; VER: 0.237 against 0.244 respectively), Table 1. Both RAD and VER EI computed from the synthetic signals underestimate the EI obtained from the recorded acceleration. The best qualitative EI fit has been observed for the RAD component, in the frequency interval 0.6 – 1 Hz.

The second comparison, fig. 5 and Table 1, shows that the synthetic TRA component significantly overestimates the observed one for all investigated ground motion parameters. The best fit in terms of PGA, PGV, Arias intensity, A95 and PGV/PGA has been observed for the RAD component (e.g. PGA = 16.7 computed against 18.2 cm/s^2 observed). All the investigated RAD ground motion parameters, derived from the synthetic signal, except the PGA/PGV ratio, are lower than the corresponding values, obtained from the recorded signal. The computed RAD SA 5% are larger than the observed one for frequencies between 1 and 2 Hz. Very good EI fit of synthetics and observation is observed for the RAD component over the frequency interval 1.25 - 2.25 Hz. The VER component shows lower synthetic values for all studied parameters, except the Arias intensity and A95. The best VER fit has been observed for PGA and PGV (Table 1).

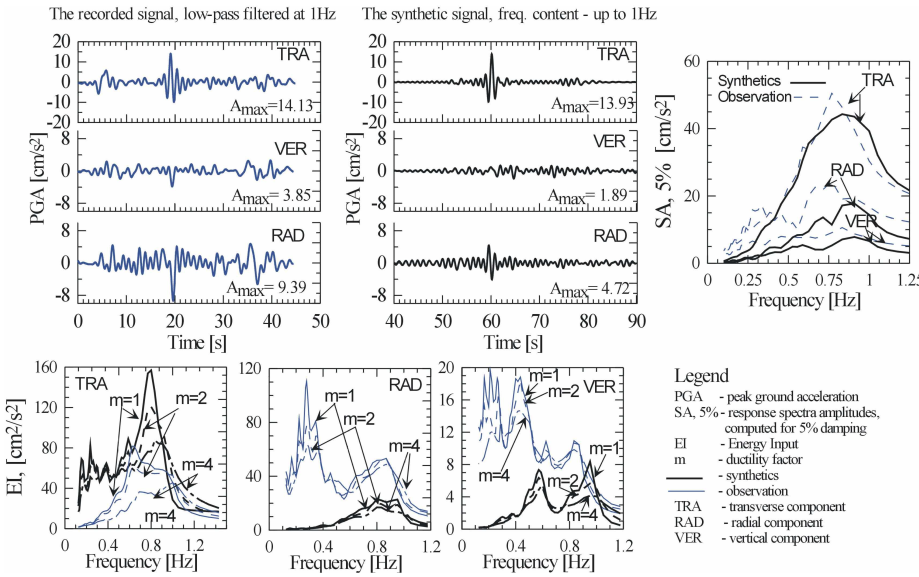

Figure 4. Vrancea earthquake, May 30, 1990, Russe recording station, NE Bulgaria. Comparison between the computed and observed signals, frequency up to 1Hz considered. *Top-Left:* The recorded accelerogram, low-passed filtered with cut-off frequency of 1Hz. *Top – middle:* The computed accelerograms. *Top-Right:* Comparison between both computed (solid lines) and observed (dashed lines) response spectra, computed for 5 % damping. *Bottom:* Comparison between synthetic (thick line) and observed (thin line) absolute energy input, computed for different ductility factors m = 1, 2 and 4. Transverse (TRA), radial (RAD) and vertical (VER) ground motion component are shown.

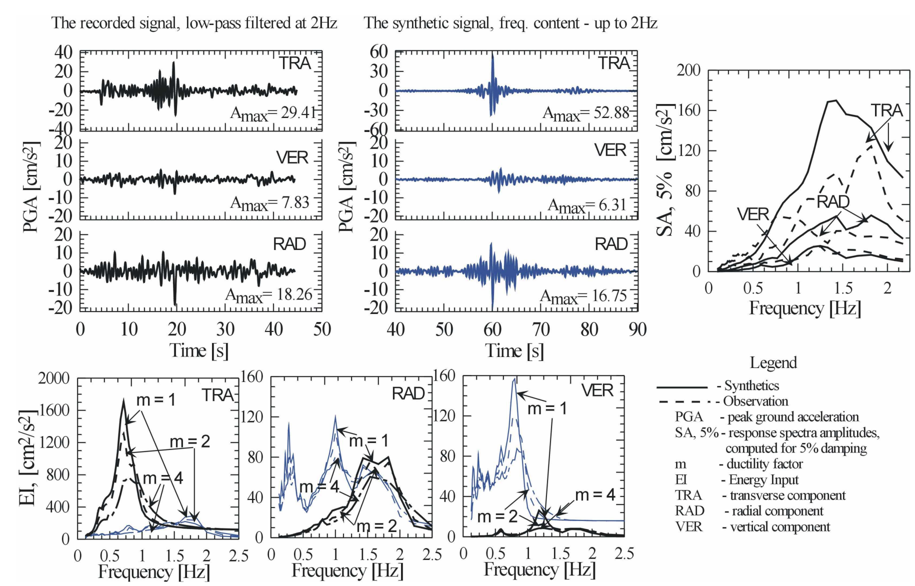

Figure 5. Vrancea earthquake, May 30, 1990, Russe recording station, NE Bulgaria. Comparison between the computed and the observed signals. Frequency up to 1Hz are considered. *Top-Left:* The recorded accelerogram, low-passed filtered with cut-off frequency of 1Hz. *Top – middle:* The computed accelerograms. *Top-Right:* Comparison between both computed (solid lines) and observed (dashed lines) response spectra, computed for 5 % damping. *Bottom:* Comparison between both synthetic and synthetic absolute energy input, computed for different ductility factors m=1, 2 and 4. Transverse (TRA), radial (RAD) and vertical (VER) ground motion component are shown.

Table 1.
Comparison between the synthetic and the observed signals in terms of representative ground motion parameters. The shadowed values correspond to the theoretical signals.

Ground motion component	PGA [cm/s^2]	PGV [cm/s]	PGD [cm]	Arias Intensity cm/s	A95 [g]	PGV/PGA [s]
1	2	3	4	6	7	8
Frequency up to 1 Hz considered						
TRA						
Vrs2dh1t	13.90	3.01	0.94	0.228	0.0137	0.216
Rsf010t	14.10	2.95	0.80	0.414	0.0140	0.209
RAD						
Vrs2dh1r	4.38	1.02	0.25	0.064	0.0042	0.233
Rsf010r	9.40	2.50	0.96	0.246	0.0092	0.266
VER						
Vrs2dh1v	1.90	0.45	0.19	0.021	0.0018	0.237
Rsf010v	3.90	0.95	0.48	0.060	0.0038	0.244
Frequency up to 2 Hz considered						
TRA						
Vrs2dh2t	52.80	12.40	3.85	3.763	0.0517	0.235
Rsf020t	29.40	4.66	1.04	1.714	0.0289	0.159
RAD						
Vrs2dh2r	16.70	2.38	0.45	0.494	0.0162	0.142
Rsf020r	18.20	2.40	0.93	0.657	0.0179	0.132
VER						
Vrs2dh2v	6.30	0.94	0.19	0.080	0.0061	0.149
Rsf020v	7.80	0.95	0.48	0.150	0.0038	0.121

CONCLUSIONS

The Vrancea seismic record and the recently constructed deterministic maps show that the seismic hazard in NE Bulgaria is mainly controlled by the large Vrancea intermediate-depth earthquakes. Different structures, located at epicentral distances of about 250km far from these sources may be prone to severe earthquake hazard. An advanced deterministic ground motion modelling technique has been proved to be capable to provide theoretical seismic loading, applicable for engineering purposes, exploiting the large quantities of already available data about sources and media crossed by waves. The method discussed addresses the issue of the deterministic definition of ground motion in a way, which permits a generalization to locations in which there is little or none seismic history. This philosophy is a result of the progress in the fields of geophysics, seismology and earthquake engineering and has been recently independently encouraged both by seismologists and engineers.

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