Acta Geod. Geoph. Hung., Vol. 41(3–4), pp. 425–431 (2006)
DOI: 10.1556/AGeod.41.2006.3–4.13

MODERN EVALUATION OF THE SEISMIC HAZARD FOR THE ROMANIAN PLAIN

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A new technique is developed to perform a deterministic hazard analysis in terms of physical parameters, i.e. displacements, velocities, maximum accelerations, and civil engineering specific ones, design accelerations. The method is adapted for the specific features of the Romanian Plain seismicity including the latest theoretical results in both seismotectonic and prediction fields, and data acquisitions. The deterministic analysis is performed computing free surface synthetic seismograms corresponding to different seismic sources and structural models, for crustal and intermediate-depth events separately. The DGA (design ground acceleration) greatest values and the NS and EW components resultant for the velocities and horizontal displacements are considered as a measure for seismic hazard level.

Keywords: deterministic hazard analysis; Romanian Plain; synthetic seismograms

Introduction

The earthquakes with proved destructive potential for the Romanian Plain are only the Vrancea intermediate-depth ones. The moderate seismicity characterizing the other crustal sources (Banat, Crisana-Marmures, Fagaras-Campulung) doesn't show the possibility to record the effects of a strong events. Taking into account the Shabla area effects (situated in the neighbouring country, Bulgaria) it is neccesary to perform a separate hazard analysis for the Cernavoda Electric Power Plant (studies in this direction already exist (Marmureanu et al. 2004)). A different method, based on the approach proposed by Costa et al. (1993) and fully refined and updated by Panza et al. (2001) which already gave good results for different crustal earthquakes produced in Italy (Panza et al. 1996), Algeria (Aoudia et al. 1996), Slovenia

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(Zivcic et al. 2000), Hungary (Bus et al. 2000), Bulgaria (Orozova-Stanishkova et al. 1996), is successfully used, consisting in a deterministic method applied to compute seismic hazard for the Romanian Plain.

Input data

In our analysis the chosen reference earthquake is August 30, 1986 event ($M_W = 7.1$, 131 km hypocentral depth) with a fault plane solution similar to other strong events which affected the Romanian Plain in the last century and recorded at 18 seismic stations (much more than others). For the seismic hazard evaluation is necessary to be known the source parameters and the parameters of the medium through seismic energy released by source is propagated to surface. This could imply a strong attenuation/amplification of the displacement amplitude and a significant change in the seismic waves field spectral content.

Seismic hazard modeling

In the sedimentary superficial structures modeling a stack of layers is used with varying thickness and constant density, seismic waves velocities and quality factors. For the crystalline bedrock modeling layers with thickness of about several kilometers are used. The modal summation technique is used to simulate synthetic accelerograms and to validate propagation structure models. The synthetic accelerograms had been scaled for the $M_0 = 6 \cdot 10^{19}$ N·m corresponding to the $M_W = 7.1$ magnitude. The seismic tomography of the Vrancea seismic region (Popa et al. 2001) suggests an increasing from 4.25 to 4.4 km/s for the S-wave velocity in the low velocity channel existing for the whole Extra-Carpathic structures and a decreasing from 4.25 to 4.15 km/s for the Intra-Carpathic structures (Radulian et al. 2002a). The quality factors QS have to be correlated with these velocities. The tomography and the recent seismic refraction experiments contributed with new features with respect to the structure models used in the seismic hazard assessement for the interest zone in the previous work (Radulian et al. 2002a, Radulian et al. 2000). The computation is made starting with the structural model and the chosen seismic sources. The synthetic seismograms for P-SV and SH waves are computed separately using modal summation technique (Panza 1985, Florsch et al. 1991). The signal frequency is limited between 0.005 to 1 Hz. The seismic hazard is computed in terms of maximum displacement ($d_{\max}$), maximum velocity ($v_{\max}$) and design ground acceleration (DGA). The seismic sources are considered to be inside the Vrancea seismogenic zone, taking into account the most recent geological, tectonics and seismological informations. The synthetic signals are computed at 1 Hz frequency in a spatial grid covering both Romanian Plain and adjacent seismogenic zones (grid step is 0.2° in both latitude and longitude). The seismic moment associated to each source is obtained using Costa et al. (1993) and Panza et al. (2001) approach. Earthquakes catalogue used is ROMPLUS (Oncescu et al. 1999) continously updated by NIEP (www.infp.ro). For the fault plane solution Radulian et al. 1996 catalogue (Radulian et al. 2002b) is considered which refers to

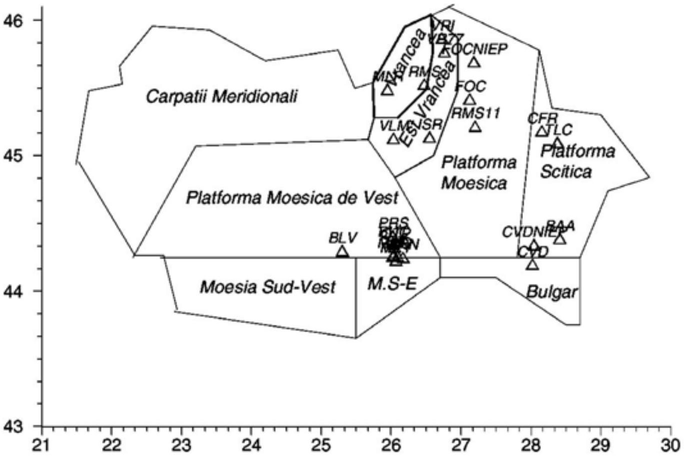

Fig. 1. Bedrock structures in the Romanian Plain. Modified after Radulian et al. (2000)

the earthquakes from 1929 to 1995. The synthetic seismograms thereby obtained are scaled to the maximum possible magnitude evaluated to the corresponding seismogenic zone using the Gusev curves modified for the Vrancea intermediate depth events (Gusev et al. 2002). The simulations was performed separately for the Romanian Plain densely populated cities, including Bucharest. In order to extend deterministic analysis to frequency above to 1 Hz a standard spectral response is used (Panza et al. 1996). Everywhere it was possible the primary synthetic signals were calibrated to reference earthquake (August 30, 1986), filtered in 0.05–1 Hz frequency domain. This was made possible for the city of Bucharest where we had 11 seismic recordings of signals for the August 30, 1986 event. For this event it is well known the seismic signal propagation structure from intermediar-depth source to the bedrock under the city site and the local geological structure. The Romanian Plain zones not covered by the seismic stations was made a comparation of the simulated signals to macroseismic intensities post-event reported or historically evaluated.

Conclusions

Recordings at 33 seismic stations were analyzed (Fig. 1). The recordings and the derived parameters (acceleration, velocity, displacement, response spectra) were filtered in the simulations frequency domain and used to validate, to modify or to improve the structural models used in simulations of the synthetic signals.

The simulation have been made for the three components, radial (R), vertical (V) and transversal (T), in terms of acceleration, velocity and surface displacement. Furthermore, it was computed the response spectra for the locations where the synthetic accelerograms were obtained for damping 0%, 5%, 10%, 20%. The distribution of the values synthetically simulated follows the real values distribution recorded at the same seismic stations. For example in Figs 2–4 the relative errors are presented between the maximum amplitude of the synthetic signals and the recorded

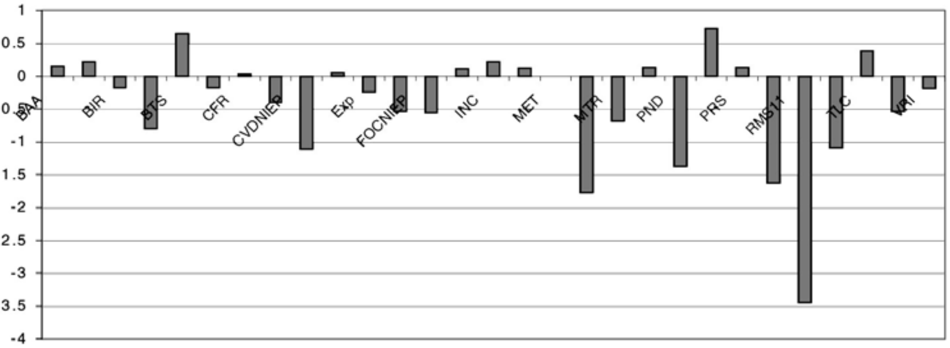

Fig. 2. Relative errors between the maximum amplitude of the synthetic signals and the recorded radial components

ones for each station used in simulation. The relative errors of the absolute maximum values for each component (R, V, T) of the seismic motion are considered acceptable for the deterministic hazard analysis. The similarity between relative error values for the FOC, CMN11, CMN21, Bucharest and the city surrounding stations, localized on the same geological structure, lead us to the conclusion that the maximum simulated synthetic signals follow the same territorial distribution as the real recorded ones (for the same events), which is encouraging to us for future studies.

The numerical models for the reference earthquake simulation validated by available recordings have been subsequently used to simulate Vrancea intermediate-depth characteristic seismic events (earthquakes scenarios). The output of this studies, consisting in maximum values of the seismic ground motion, is of great importance in general seismic hazard map of the Romanian territory and a major instrument in the global seismic response prediction for a future event that may occur in Vrancea seismogenic zone. Two types of seismic source have been analyzed for this purpose: 1. with a 90 km focal depth, magnitude $M_W = 7.1$ and a focal mechanism corresponding to the March 4, 1977 Vrancea seismic event; 2. located at the plate bottom, 150 km deep, magnitude $M_w = 7.7$, with the same focal mechanism as the event of August 30, 1986. The two types of foci considered are typical for Vrancea earthquakes, and the two focal mechanisms are almost identical. We believe that they both have the same parameters of the fault plane: strike 225°, dip 60°, rake 80°. The choice of this fault plane is motivated by the fact that 90% of events are characterized by such focal mechanisms having an almost vertical T axis and an almost horizontal P axis.

The simulations of these seismic scenarios are complete in displacements velocities and accelerations at soil surface, though only the distribution of the maximal values of DGA for each of these scenarios are given in Figs 5 and 6, respectively. One can see for such type of earthquakes the local minimum in the epicentral region, this being an important effect of the intermediate earthquakes.

For source 1 the highest values are obtained in all the three cases at the SE of the epicentral area (0.3 g for DGA and acceleration, 42 cm for displacement,

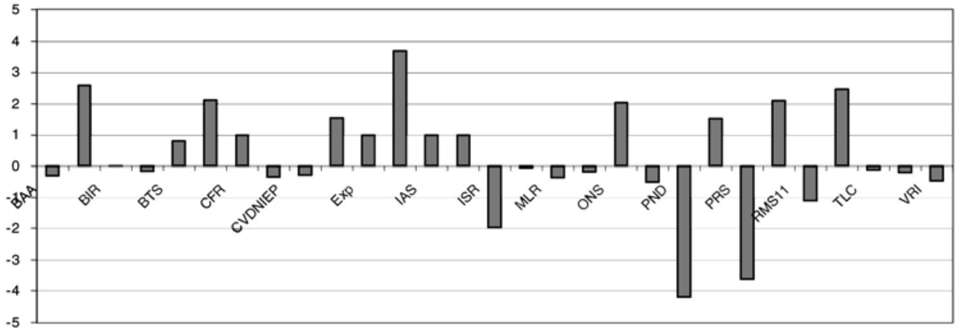

Fig. 3. Relative errors between the maximum amplitude of the synthetic signals and the recorded vertical components

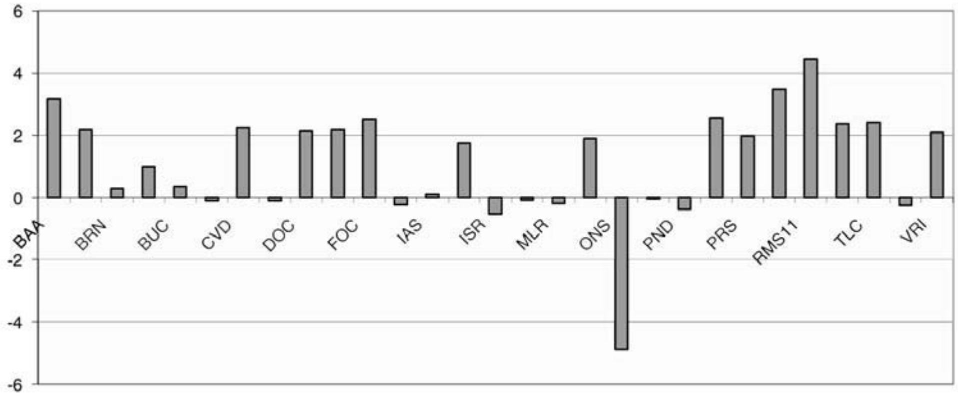

Fig. 4. Relative errors between the maximum amplitude of the synthetic signals and the recorded transversal components

100 cm/s for velocity). These high values are distributed over an extended area, E from Galatzi toward W at Targoviste. Maximum values are obtained near Ploiesti, 60 km N of Bucharest (0.44 g DGA). For Bucharest the 0.23 g DGA corresponds to intensity VIII, as observed also in 1977. Values higher than 0.2 g occur in S and SE (44.4° N and $26 - 28°$ E), which affect most of the Moesian Platform.

In general, the distribution of the amplitudes for source 2 is similar with that corresponding to source 1. One can see effects due to the difference in focal depth: the minimum zone around the epicentre is larger, the highest values zone is further away from the epicentre. In general, for a greater depth the attenuation is smaller at larger epicentral distances. The ground motion in Bucharest is higher: 0.52 g DGA. Higher values occur in the Scithyan Platform, the Moesian Platform (higher than 0.3 g DGA). In Vrancea NW there are smaller DGA values than in the first case.

Though the effects are very different for the two sources, the overall picture for the distribution of the seismic hazard is not changed. For source 1 the values

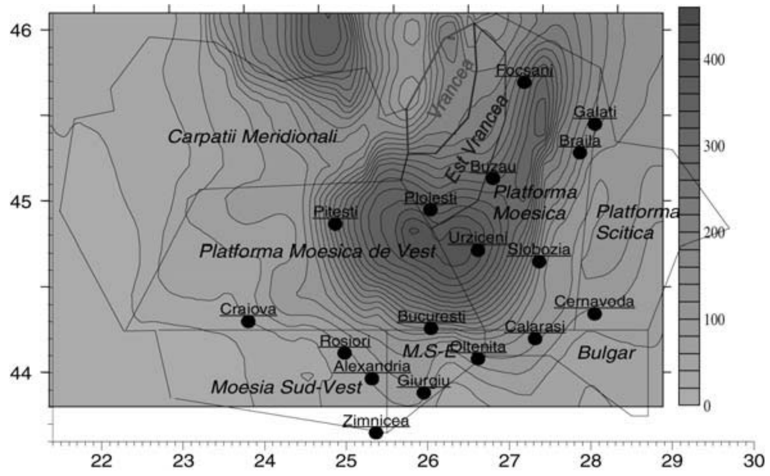

Fig. 5. The DGA distribution over the Romanian Plain for the source 1 scenario

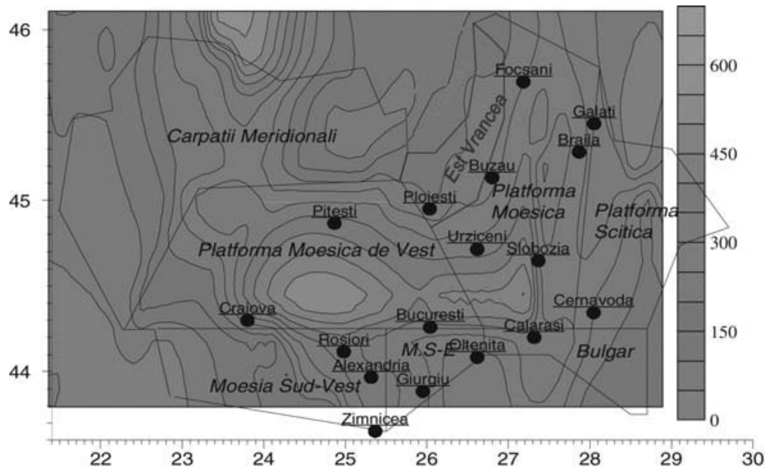

Fig. 6. The DGA distribution over the Romanian Plain for the source 2 scenario

are smaller than for source 2, because the effects are larger for larger epicentral distances and a deeper source. We can say that seismic hazard is much affected by depth and magnitude.

The deterministic analysis for seismic hazard, applied to various locations corresponding to the same seismogene zone, does not yet account for the local seismic effects, due to structural inhomogeneities of relatively small dimensions, or to the presence of freatic water, or topography. In estimating the seismic risk for densely populated localities in the Extra-Carpathian territory it is essential to corroborate the results of the determinist and the results of classical hazard, which accounts for the seismic history of the place, i.e. the time factor. It is necessary that, when elaborating seismic hazard maps for urban locations, the urbanism and territorial administration services be consulted, in order to attain an adaptation to the requirements resulting from PANT/2001 Romanian law, Natural Risk Zones, which bear relevance upon the manner of elaboration of the plans of territory regularization. The computations have been made starting from the structural model and seismic source chosen separately for the crustal and the intermediate-depth strong events. For each urban area located in the Romanian Plain it was considered all potentialy dangerous seismic sources and, as a measure for the seismic hazard, the highest DGA value and the resulting value for the NS, EW horizontal displacement and velocity components. For maximum 15% relative errors between the synthetic signals amplitudes and the recorded amplitudes the computational modeling was considered acceptable. Next the calibration was done for the simulations of the real recordings and the corresponding values were represented on the Romanian Plain map. The results will be used in Romanian seismic map development, an important background in increasing earthquake preparedness and seismic risk mitigation. This knowledge can be very fruitfully used by civil engineers in the design of new seismo-resistant constructions and in the reinforcement of the existing built environment.

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