SHAKE MAPS OF STRENGTH AND DISPLACEMENT DEMANDS FOR ROMANIAN VRANCEA EARTHQUAKES

D. Lungu[1] and I.-G. Craifaleanu[2]

[1] *Professor, Dept. of Reinforced Concrete Structures , Technical University of Civil Engineering & National Institute for Historical Monuments, Bucharest. Romania*
[2] *Associate Professor, Dept. of Reinforced Concrete Structures, Technical University of Civil Engineering & National Institute for Building Research, Bucharest, Romania*
Email: iolanda@incerc2004.ro, i.craifaleanu@gmail.com

ABSTRACT :

The paper presents results from an extensive study, involving the mapping of key ground motion parameters and of linear/nonlinear spectral ordinates for all strong Vrancea earthquakes which occurred in Romania in the last three decades. The study is intended to provide a comprehensive image on the spatial distribution of the considered parameters, based on available ground motions records from the 1986 (M_w=7.2), 1990 (M_w = 7.0) and 2004 (M_w = 6.0) earthquakes. The paper focuses on the analysis of the spatial distribution of strength and displacement demands for the analyzed earthquakes, based on linear/nonlinear spectral ordinates for acceleration and displacement. By corroboration with data from previous research carried out by the authors, the study reveals interesting conclusions for structural design.

KEYWORDS: shake maps, Vrancea earthquakes, strength demands, displacement demands

1. INTRODUCTION

Nonlinear response spectra are an important source of information on seismic demands on buildings. While the "usual" study of these spectra has long been used in earthquake engineering research, the mapping of nonlinear spectral ordinates, in order to assess the spatial distribution of relevant parameters of seismic response, is a relatively new approach.

The paper presents results from a study performed on ground motion recorded during the strong earthquakes which occurred in the Vrancea seismic zone of Romania during the last three decades. Linear and nonlinear spectral ordinates of acceleration and displacement were mapped, for a set of significant values of structure period and ductility. Then, based on map ordinates, interpolation surfaces and contours of constant values were determined by using specialized GIS software.

The following Vrancea events were considered: August 30, 1986 (moment magnitude M_w = 7.1, focal depth h = 133 km), May 30, 1990 (M_w = 6.9, h = 91 km) and May 31, 1990 (M_w = 6.4, h = 79 km) and October 27, 2004 (M_w = 6.0, h = 96 km). As the largest demands, both in terms of acceleration and of displacement, occurred, generally, for the August 30, 1986 earthquake, the strongest seismic event considered, the presentation will focus on the results obtained for this earthquake.

2. MAPS OF ELASTIC AND INELASTIC RESPONSE SPECTRUM ORDINATES

2.1. Basic assumptions

Response spectrum ordinates were computed for a damping ratio of 5% and three values of structure period

(T = 0.5, 1.0 and 1.5 s).

Inelastic behavior was modeled by considering a simple elastic-perfectly plastic hysteretic model. Spectral values were calculated for a set of specified values of ductility, i.e. μ = 1 (elastic behavior) and μ = 1.5, 2, 3, 4, 5 and 6 (inelastic behavior).

Interpolation surfaces were generated strictly on the area delimited by the extreme seismic station points. Therefore, due to the distribution of recording stations at the date of the earthquake, results were obtained only for the eastern part of the country.

The study focused on spectral accelerations and spectral displacements, in order to explore the spatial distribution of seismic demands on building structures with different stiffness and ductility characteristics.

The strong variability of response spectrum ordinates due to different factors complicates discerning general tendencies; however, the results of previous studies on linear/nonlinear spectra for the ground motions considered provide a reliable source of information.

One of the most important observations in the previous studies on nonlinear spectra concerns the variation of acceleration and displacement ordinates with ductility, μ, and structure period, T. While acceleration ordinates decrease with the increase of ductility, the variation of displacement ordinates with this parameter is non-monotonous. As for the variation of spectral ordinates with structure period, this depends primarily on the spectral contents of the ground motion. However, for displacements, at short periods, a general tendency of increasing of spectral ordinates with period was observed. These typical characteristics are clearly illustrated by the nonlinear acceleration and displacement spectra in Fig. 1 a) and b).

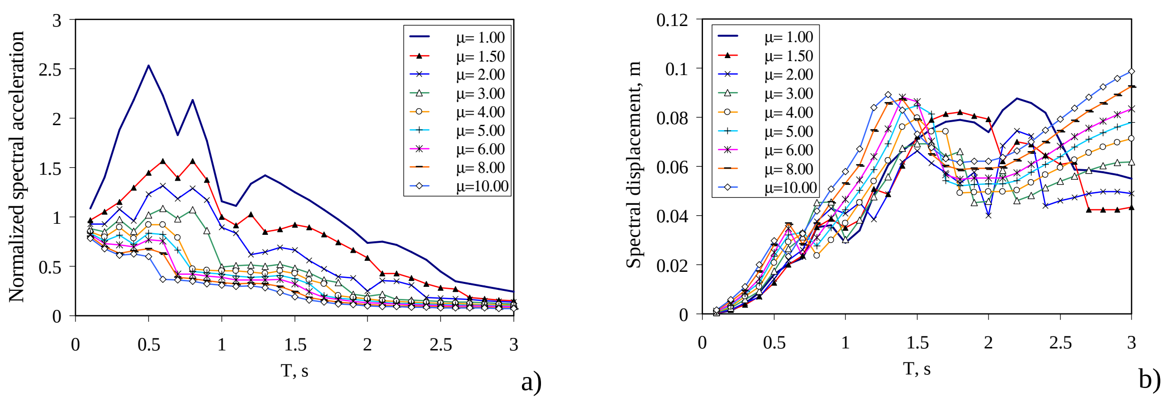


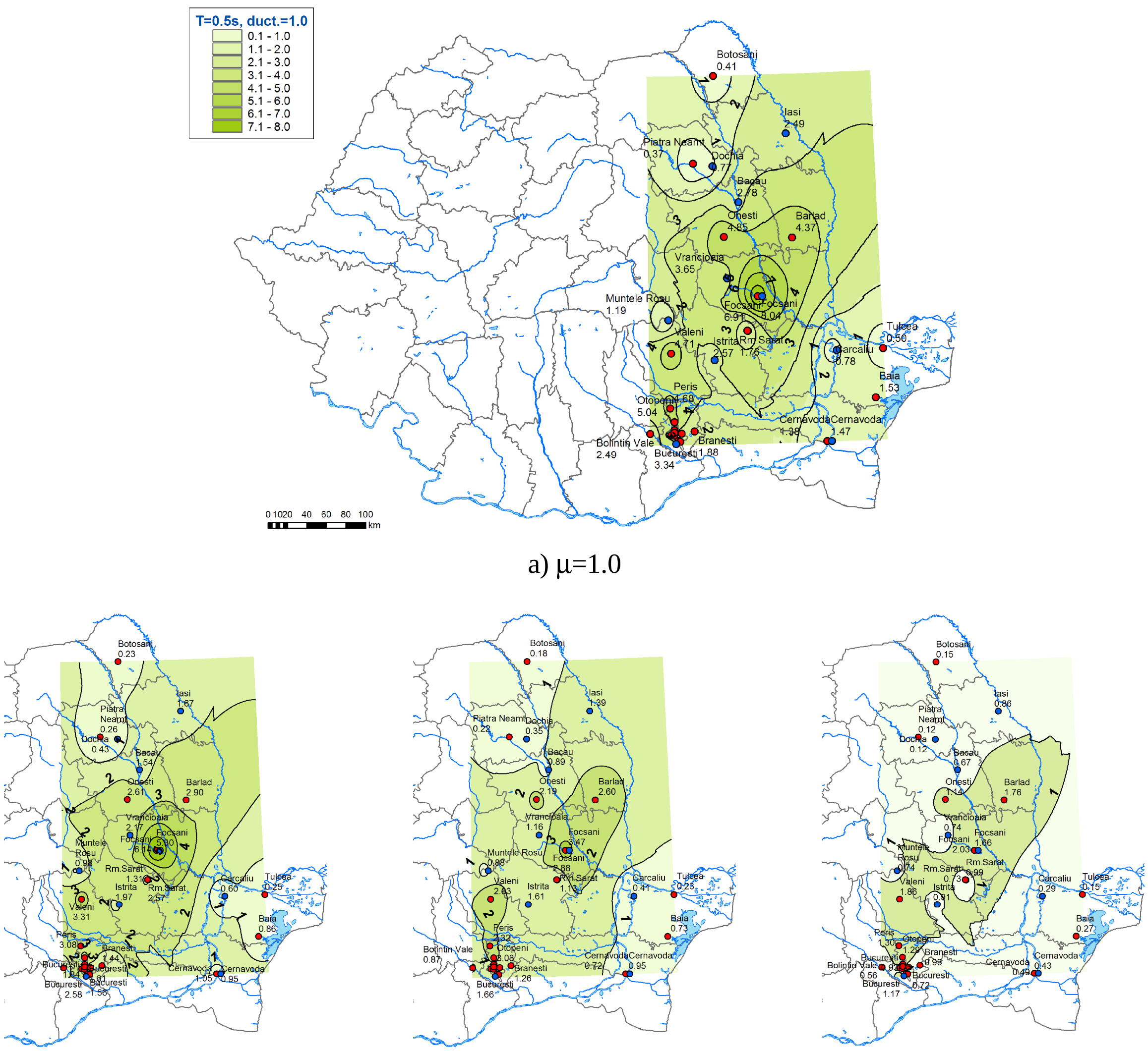
Figure 1. Typical nonlinear acceleration and displacement spectra. August 30, 1986, INCERC Bucharest, NS component

The above observations facilitate interpretation of the results presented in the following paragraphs.

2.2. Spectral Accelerations

Maps of elastic and inelastic spectral acceleration ordinates for the earthquake of August 30, 1986 are shown in Figs. 2 to 6, for structure period T = 0.5 s and 1.5 s. Units for spectral accelerations are m/s^2.

In order to better illustrate the variation of spectral ordinates with ductility, 3D representations of the interpolation surfaces were also generated (Fig. 3).



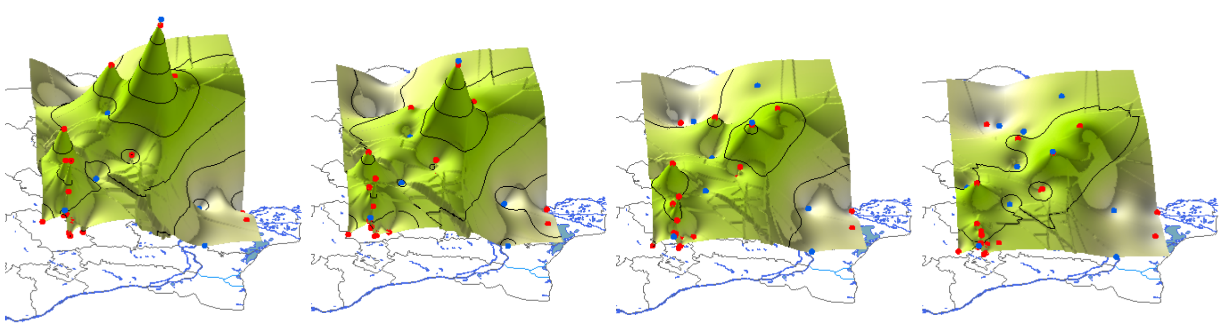
a) μ=1.0

b) μ=1.5

c) μ=2

d) μ=4

Figure 2. August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ =1.5, 2.0, 4.0) spectral acceleration for structure period $T = 0.5$ s



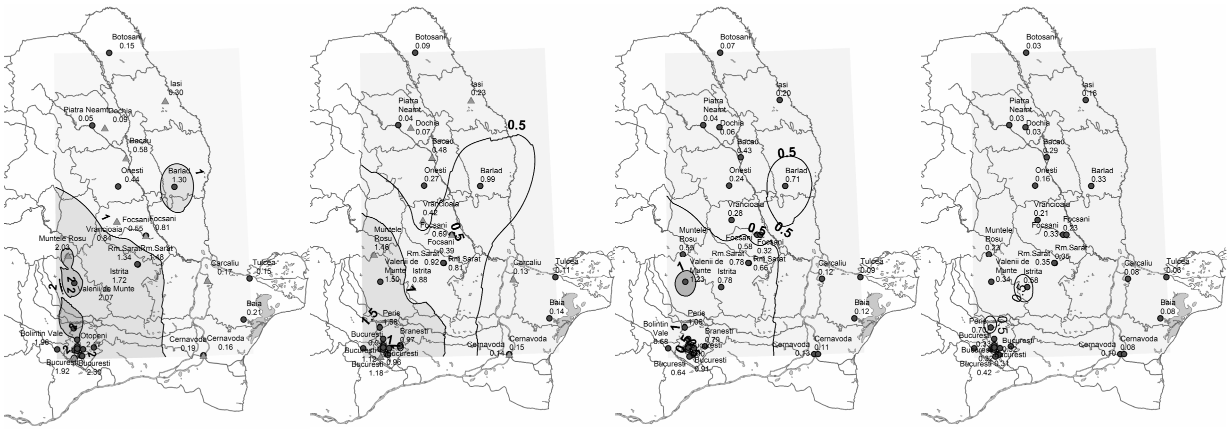
a) μ=1.0

b) μ=1.5

c) μ=2

d) μ=4

Figure 3. 3D representation of the interpolation surfaces in Fig. 2



a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 4. August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral acceleration for structure period T = 1.5 s

By examining the maps, a clear tendency of decreasing spectral ordinates with an increase in ductility can be observed. The spatial distribution of spectral accelerations becomes more and more uniform as ductility increases. This phenomenon can be observed on all maps, irrespective of the structure period for which the spectral ordinates were computed. However, the interpolation surface does not flatten uniformly, as the rate of variation of spectral ordinates with ductility is different from one ground motion record to another (Fig. 3).

The structure vibration period does also have an important influence on spectral accelerations. However, in the long period range, i. e. for T=1.5 s, the amplitude of this variation attenuates considerably, as a consequence of the frequency contents of the ground motions analyzed (Fig. 4).

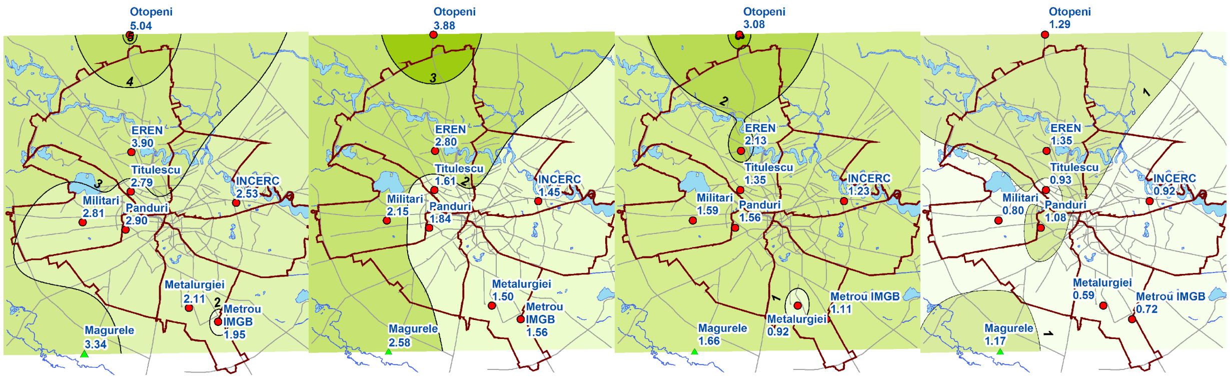
Contour maps are also sensitive to factors like the number of stations that provided seismic records and the values of the numerical parameters used to generate the interpolation surface.

One of the most significant consequences of the observations above is that for building structures with inelastic behavior, the spatial distribution of seismic strength demand is more uniform than for structures behaving elastically. As a result, for common structures for which inelastic behavior is allowed for the design earthquake, the influence of the other factors affecting spatial distribution is less important than anticipated.

Detailed analyses of inelastic response spectra for the Vrancea seismic motions considered in the present study can be found in Lungu et al.(1996) and Craifaleanu (1996-2005).

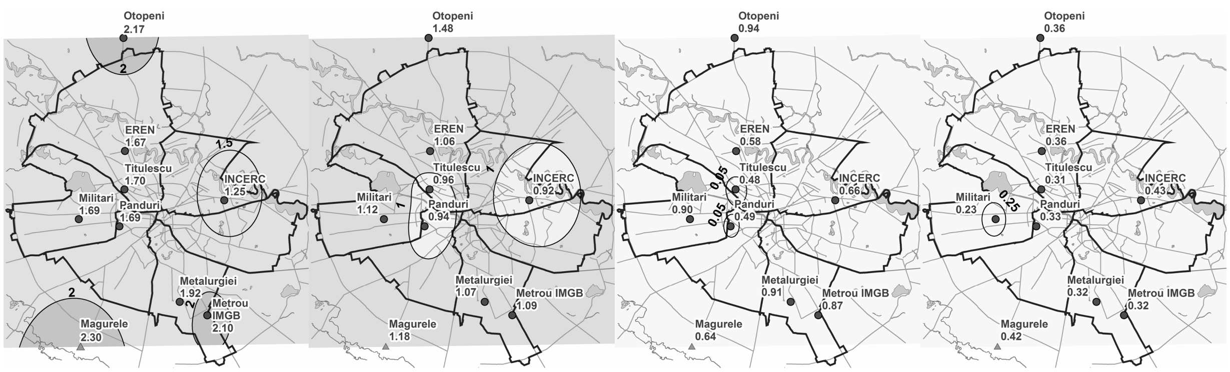
Apart from the previous observations, it is also worth noting for the maps of Romania (Figures 2 and 4) that the northeast-southwest orientation of map contours for the 1986 earthquake is similar to that observed on the maps of PGA, EPA and EPV for the same seismic event. This observation was made in a previous paper (Craifaleanu et al., 2006).

Views of the spatial distribution of spectral accelerations in Bucharest are shown in Figs. 5 and 6.



a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 5. Bucharest, August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral acceleration for structure period T = 0.5 s



a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 6. Bucharest, August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral acceleration for structure period T = 1.5 s

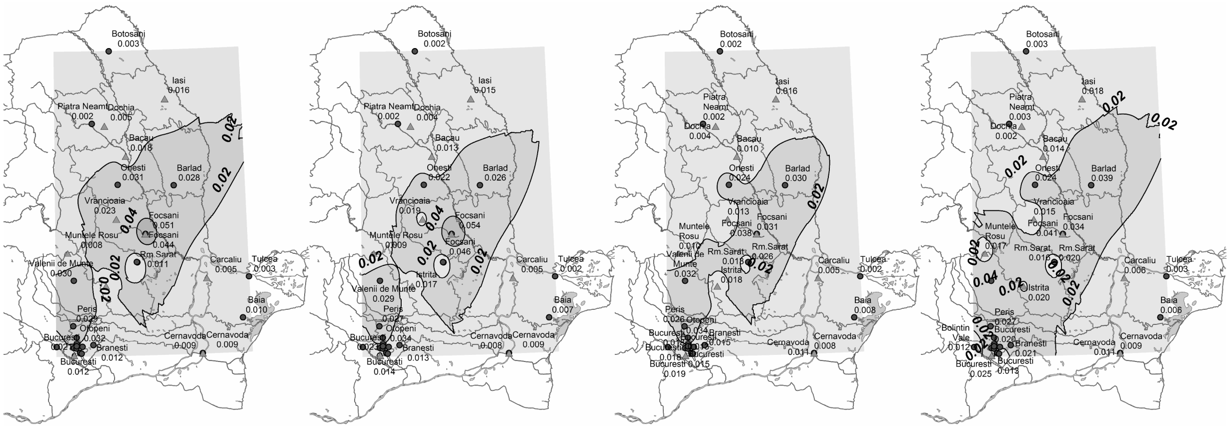
2.3. Spectral Displacements

Maps of elastic and inelastic spectral displacement ordinates are shown in figures 7 to 11 for the August 30, 1986 earthquake. Units for spectral displacement are meters.

The variation of spectral ordinates with ductility is non-monotonous; therefore, a general conclusion cannot be drawn concerning the influence of this factor. Consequently, the beneficial effect of inelastic behavior described for spectral accelerations does not apply for spectral displacement maps. In what concerns the influence of the structure period, there is a marked increase of displacement ordinates with this parameter.

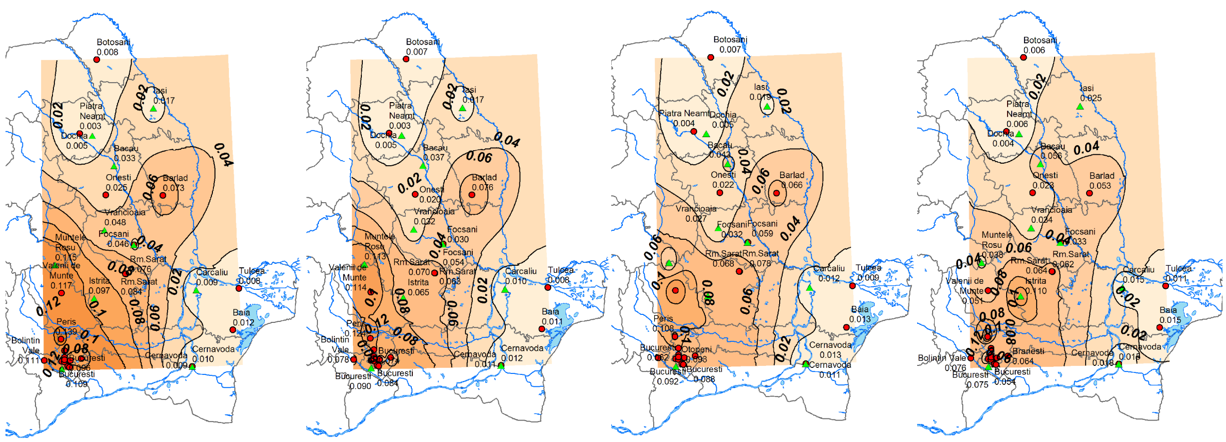
The above remarks, which are consistent with previous studies on inelastic displacement spectra, can be made with respect to both Romania and Bucharest contour maps.

It is worth noting that the previous observation concerning the northeast-southwest orientation of map contours can also be made for spectral displacements.



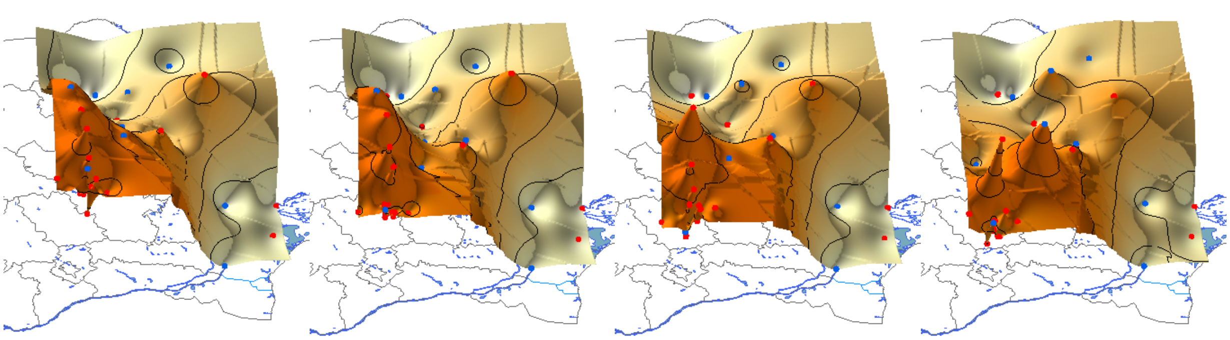
μ=1.0 μ=1.5 μ=2 μ=4

Figure 7. August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral displacement for structure period *T* = 0.5 s



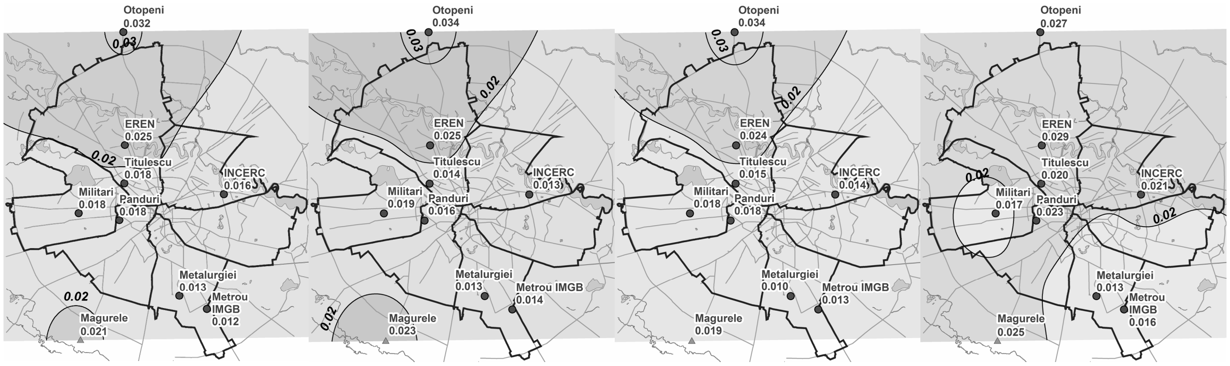
a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 8. August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral displacement for structure period *T* = 1.5 s



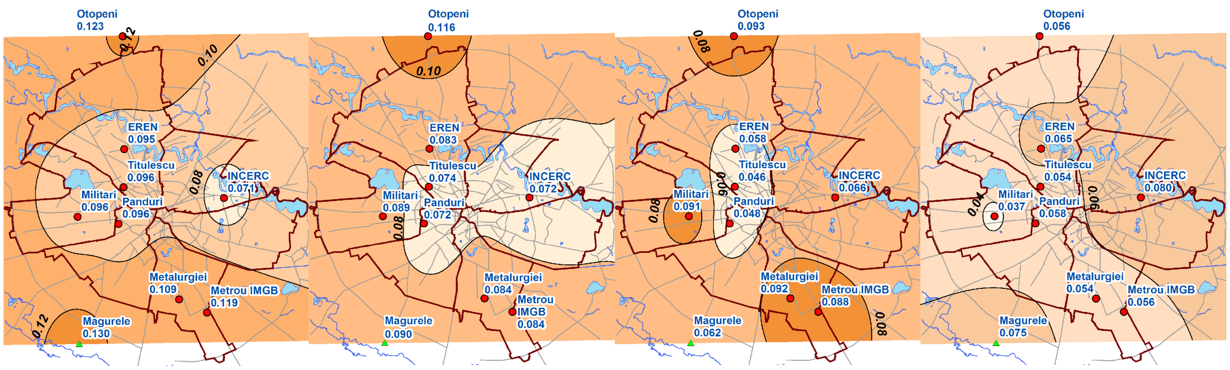
a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 9. 3D representation of the interpolation surfaces in Fig. 8



a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 10. Bucharest, August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral displacement for structure period T = 0.5 s



a) μ=1.0 b) μ=1.5 c) μ=2 d) μ=4

Figure 11. Bucharest, August 30, 1986 earthquake. Distribution of elastic (μ=1.0) and inelastic (μ=1.5, 2.0, 4.0) spectral displacement for structure period T = 1.5 s

3. CONCLUSIONS

1. The dynamic characteristics of the structure have a strong influence on the spatial distribution of strength and displacement demands. The influence observed on the map is consistent with the results obtained from previous studies on nonlinear spectral response.

2. With the increase of ductility, strength demands attenuate significantly and their spatial distribution becomes more and more uniform. This means that, for common structures, for which inelastic behavior is allowed for the design earthquake, the influence of the other factors affecting spatial distribution of strength demands is less important than anticipated.

The above conclusions highlight the importance of structural characteristics on the spatial distribution of strength and displacement demands imposed by earthquakes. In certain cases, the influence of structural characteristics can prevail on those of factors related to ground motion, especially for buildings that exhibit relatively large post-elastic incursions during a seismic event.

ACKNOWLEDGEMENTS

This research was partly sponsored by NATO's Scientific Affairs Division in the framework of the Science for Peace Programme, project SfP-980468.

REFERENCES

Craifaleanu, I. G. (1996). Contributions to the Study of Inelastic Seismic Response of Reinforced Concrete Structures. PhD Thesis. Technical University of Civil Engineering, Bucharest (in Romanian).

Craifaleanu, I. G. (1999). Studies on Inelastic Response Spectra for Vrancea Earthquakes. *Buletinul AICPS* **10:3**, 62-68 (in Romanian).

Craifaleanu, I. G. (2001). A Perspective on the Use of Inelastic Response Spectra in Building Design. *Buletinul AICPS* **12:3**, 8-19 (in Romanian).

Craifaleanu, I. G. (2005). Nonlinear Single-Degree-of-Freedom Models in Earthquake Engineering. Matrix Rom Publishers. Bucharest (in Romanian).

Craifaleanu, I. G., Lungu, D., Borcia, I. S. (2006). Shakemaps of Nonlinear Spectral Ordinates for Vrancea Earthquakes. Proceedings of the First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, 3-8 September, Paper No.1257 (on CD-ROM).

Lungu, D., Cornea, T., Craifaleanu, I., Aldea, A. (1995). Uniform hazard response spectra in soft soil condition and Eurocode 8. 7th International Conference of Application of Statistics and Probability in Civil Engineering, Reliability and Risk Analysis, ICASP-7, Paris, July 10-13, Proceedings, Vol. 1, p. 619-626, A. A. Balkema, Rotterdam.

Lungu, D., Cornea, T., Craifaleanu, I., Demetriu, S. (1996). Probabilistic seismic hazard analysis for inelastic structures on soft soils. Proceedings of the Eleventh World Conference on Earthquake Engineering, Acapulco, Mexico, June 23-28, Paper No. 1768 (on CD-ROM).

Lungu, D., Cornea, T., Aldea, A., Nedelcu, C., Demetriu, S. (1999). Uncertainties in mapping frequency content of soil response to various magnitude earthquakes. EUROMECH 372 Colloquium of the European Mechanics Society, Reliability in Nonlinear Structural Mechanics. 21-24 Oct., Université Blaise Pascal, Institut Français de Mécanique Avancée, Clermont-Ferrand, France, 39-48.

Lungu, D., Aldea, A., Demetriu, S. (2005). City of Bucharest: Seismic hazard and microzonation of site effects. Proceedings of the International Conference dedicated to the 250th Anniversary of the 1755 Lisbon Earthquake, (on CD-ROM).

___ Seismic Database for Romanian Earthquakes (2001). National Institute for Building Research, INCERC, and National Institute for Earthquake Physics, INFP. Research founded by the Romanian Ministry of Education and Research.