13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 1796

REPREZENTATION OF SEISMIC ACTION IN THE NEW ROMANIAN CODE FOR DESIGN OF EARTHQUAKE RESISTANT BUILDINGS P100-2003

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SUMMARY

A proposal for a new earthquake resistant design code (P100-2003) was developed in 2003 at Technical University of Civil Engineering Bucharest. It follows EUROCODE 8 [1] format. The present paper focuses on the representation of seismic action. A predictive contour map for peak ground acceleration *PGA* was prepared using GIS technology. The map also includes the contributions of all crustal sources affecting Romanian territory. The paper presents the zonation of the control period of response spectra *Tc* for the strong ground motions recorded in Romania, and the new proposed design spectra.

INTRODUCTION

According to the number of people lost in earthquake disasters during 20th century as well as in a single event (March 4, 1977: 1574 deaths, including 1424 in Bucharest), Romania can be ranked the 3rd country in Europe, after Italy and Turkey. Romania is followed by the former Yugoslavia and by Greece (Bolt, [2] Coburn and Spence, [3]). The World Bank [4] loss estimation after the 1977 earthquake indicates that from the total loss (2.05 Billion US $) more than 2/3 were in Bucharest, capital city of Romania.

The Vrancea region, located where the Carpathians Mountains Arch bends, is a source of subcrustal seismic activity, which affects more than 2/3 of the territory of Romania and an important part of the territories of Republic of Moldova, Bulgaria and Ukraine. According to the 20th century seismicity, the epicentral Vrancea area is confined to a rectangle of 40x80km^2 having the long axis oriented N45E and being centered at about 45.6° Lat.N and 26.6° Long. E.

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The Vrancea source induces a high seismic risk in the densely built zones of the South-East of Romania. On March 4, 1977, during the most destructive Vrancea earthquake of this century, in the capital city of Romania, Bucharest, 1424 casualties were registered and 32 reinforced concrete high-rise buildings completely collapsed.

The first and the most important free-field strong ground motion in Romania was recorded at INCERC seismic station in Eastern Bucharest during March 4, 1977 Vrancea earthquake ($Mw=7.5$, $h=109\ km$, epicentral distance to Bucharest $105\ km$). The accelerogram (characterized by $0.2g$ peak ground acceleration and by $1.6s$ long predominant period of soil vibration) was recorded on a SMAC-B Japanese instrument and digitized and processed by the Observational Committee of Strong Motion Earthquake of the Building Research Institute, Japan [5].

During the last 60 years, Romania experienced 4 strong Vrancea events: Nov.10, 1940 (moment magnitude $Mw=7.7$, focal depth $h=150\ km$), March 4, 1977 ($Mw=7.5$, $h=109\ km$), Aug 30, 1986 ($Mw=7.2$, $h=133km$) and May 30&31, 1990 ($Mw=7.0\&6.4$, $h=91\&79\ km$).

SEISMIC STRONG MOTION NETWORKS OF ROMANIA

In the decade following the 1977 strong earthquake, on the territory of Romania were installed 3 strong motion networks: INCERC (National Building Research Institute), INFP (National Institute of Earth Physics) and GEOTEC (Institute for Geotechnical and Geophysical Studies). The seismic instrumentation at INCERC was developed for earthquake engineering purposes. INCERC network is the largest and the richest seismic network of Romania (in terms of number of recorded strong ground motion). The network of INFP was developed with UNESCO support. In the last decade the Geophysical Institute of Karlsruhe University installed a significant number of digital accelerometers as one of the components of the *SFB 461* German-Romanian project on Vrancea earthquakes. The GEOTEC seismic network is related to dam and hydraulic structures monitoring.

In 2003 a new seismic network of the National Center for Seismic Risk Reduction NCSRR was created in the frame of the Japan International Cooperation Agency (JICA) Technical Cooperation Project [6] "Reduction of Seismic Risk for Buildings and Structures".
A more detailed description of the seismic networks in Romania is presented in Aldea *et al.* [7].

CATALOGUES OF STRONG VRANCEA EARTHQUAKES

The catalogues of earthquakes that occurred on the territory of Romania were compiled by Radu [8] and Constantinescu and Marza [9]. The catalogues can be divided into separate catalogues corresponding to various seismic regions/zones of Romania. Of course, the majority of the events from the catalogues refers to earthquakes in Vrancea zone. The Radu’s catalogue is the most complete one, even the majority of significant events are also included in the Constantinescu and Marza catalogue. The magnitude in the Radu catalogue is the Gutenberg-Richter magnitude $M_{G\text{-}R}$. The magnitude in the Constantinescu & Marza catalogue is the surface magnitude M_S; tacitly, M_S magnitude was later assimilated as Gutenberg-Richter magnitude (Marza [10]). For Vrancea subcrustal source, the conversion of Gutenberg-Richter magnitude into moment magnitude might be approximated by $M_W=M_{G\text{-}R} + 0.3$ for $6.5 < M_W < 7.8$ (Lungu *et al.*[11]).
Radu last manuscripts containing the latest version of catalogues were processed and published in Lungu *et al*. [12]. Radu’s catalogue indicates an average of 1 event/century with maximum intensity $I_0>9.0$ during the period 984-1900 and 2 events/century with $M_{G\text{-}R}\geq 7.2$ ($I_0>9.0$) during the period 1901-2000. In Table 1 is presented an excerpt from Radu's catalogue of Vrancea earthquakes during 20th century, in comparison with data from other catalogues.

Table 1. Catalogue of subcrustal Vrancea earthquakes ($M_w \geq 6.3$), 20th century

Date		Lat. N^0	Long. E°	RADU Catalogue, 1994				MARZA Catalogue, 1980		www.infp.ro Catalogue, 1998
				h, km	I_0 [1)]	M_{GR}	M_w	I_0	M_s	M_w
1903	Sept 13	45.7	26.6	>60	7	6.3	-	*6.5*	*5.7*	*6.3*
1904	Feb 6	45.7	26.6	75	6	5.7	-	6	6.3	6.6
1908	Oct 6	45.7	26.5	150	8	6.8	-	*8*	*6.8*	*7.1*
1912	May 25	45.7	27.2	80	7	6.0	-	*7*	*6.4*	*6.7*
1934	March 29	45.8	26.5	90	7	6.3	-	*8*	*6.3*	*6.6*
1939	Sept 5	45.9	26.7	120	6	5.3	-	6	6.1	6.2
1940	Oct 22	45.8	26.4	122	7 / 8	6.5	-	*7*	*6.2*	*6.5*
1940	Nov 10	45.8	26.7	150	9	7.4	-	*9*	*7.4*	*7.7*
1945	Sept 7	45.9	26.5	75	7 / 8	6.5	-	*7.5*	*6.5*	*6.8*
1945	Dec 9	45.7	26.8	80	7	6.0	-	*7*	*6.2*	*6.5*
1948	May 29	45.8	26.5	130	6 / 7	5.8	-	6.5	6.0	6.3
1977	March 4 [2)]	45.34	26.30	109	8 / 9	7.2	7.5	*9*	*7.2*	*7.4*
1986	Aug 30	45.53	26.47	133	8	7.0	7.2	-	-	7.1
1990	May 30	45.82	26.90	91	8	6.7	7.0	-	-	6.9
1990	May 31	45.83	26.89	79	7	6.1	6.4	-	-	6.4

[1)] Maximum seismic intensity

[2)] Main shock

SEISMICITY OF THE VRANCEA SUBCRUSTAL SOURCE IN ROMANIA

Even the available catalogues of Vrancea events were prepared using the Gutenberg-Richter magnitude M_{GR}, the recurrence-magnitude relationship presented here (Lungu et al. [11]) were determined using the moment magnitude M_W. The relationship is determined from Radu's 20th century catalogue of subcrustal magnitudes with threshold lower magnitude M_W=*6.3*.

The average number per year of Vrancea subcrustal earthquakes with magnitude equal to and greater than M_W, in the Gutenberg-Richter format of magnitude recurrence relationship is given by:

$$\log n(\geq M_W) = 3.76 - 0.73\, M_W. \quad (1)$$

If the source magnitude is limited by an upper bound magnitude $M_{w,max}$ (maximum credible magnitude), the recurrence relationship can be modified into the truncated Gutenberg-Richter relationship.
For Vrancea source the truncated relationship was firstly applied using Gutenberg-Richter magnitudes (Elnashai & Lungu [13]). Using moment magnitudes, the following relation was obtained (Lungu [11]):

$$n(\geq M_w) = e^{8.654-1.687 M_w}\, \frac{1-e^{-1.687(8.1-M_w)}}{1-e^{-1.687(8.1-6.3)}} \quad (2)$$

The maximum credible magnitude of Vrancea source was estimated using Wells and Coppersmith [14] relations. The maximum values of surface rupture area (*SRA*) and surface rupture length (*SRL*) were estimated using data from past earthquakes and experts opinion, and were used with Wells and Coppersmith equations for "thrust fault" type of focal mechanism. Even those equations are intended for crustal earthquakes, the experience of subcrustal Vrancea events fits quite well the mentioned equations.

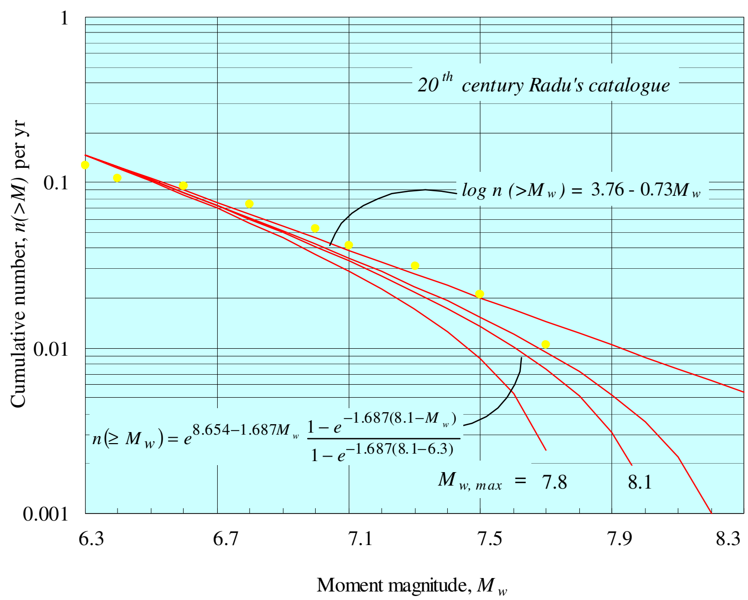

Figure 1. Magnitude recurrence relation for Vrancea subcrustal source ($M_w \geq 6.3$)

According to Romanian geologists Sandulescu & Dinu [15], in Vrancea subduction zone: $SRL \leq 150 \div 200km$ and $SRA \leq 8000\ km^2$. Based on this estimation one gets $M_{w,max}= 8.1$ (Lungu *et al*.[11]).
In *Eq.(2),* the threshold lower magnitude is $M_w=6.3$, the maximum credible magnitude of the source is $M_{w,max}=8.1$, and $\alpha = 3.76\ ln10 = 8.654,\ \beta = 0.73\ ln10 = 1.687$.

The damage intensity of the Vrancea strong earthquakes is the combined result of both magnitude and location of the focus inside the earth. In case of Vrancea source, an interesting and important correlation was noticed between the focal depth and earthquake magnitude. The relationship between the magnitude of a potentially destructive Vrancea earthquake ($M_w \geq 6.3$) and the corresponding focal depth (using Radu's 20th century catalogue) shows that higher the magnitude, deeper the focus (Lungu et al.[16]):

$$ln\ h = -\ 0.866 + 2.846\ lnM_w - 0.18\ P \quad (3)$$

where P is a binary variable: $P=0$ for the mean relationship and $P=1.0$ for mean minus one standard deviation relationship. The depth dependence of high magnitudes is plotted in Figure 2.

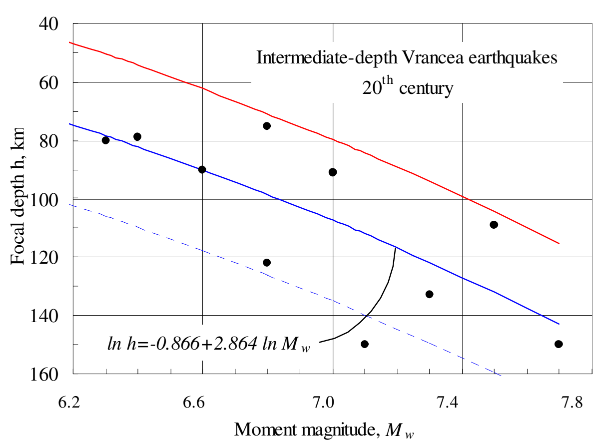

Figure 2. Correlation of large magnitude with focus depth for Vrancea source

The mean minus one standard deviation curve in Figure 2 should be used in hazard analysis as pessimistic correlation of Vrancea magnitude with focus depth. The earthquakes with $M_w \leq 6.3$ display no correlation.

ATTENUATION RELATIONS FOR THE PEAK GROUND ACCELERATION FOR VRANCEA SOURCE

The research devoted to the prediction of attenuation of Vrancea ground motions started in 1994. An increased accuracy in selection of the free-field accelerograms and the re-processing (1996-1999) of the accelerograms of INCERC seismic network allow the refinement (Lungu et al. [16]) of the previous predictions obtained at Technical University of Civil Engineering - Bucharest by Lungu *et al.* [17], [18], [19], [20].

The database used for the analysis of the Vrancea ground motions attenuation contains 71 accelerograms recorded at 47 free-field stations in Romania. The database was completed with 9 free-field accelerograms recorded in Rep. of Moldova and Bulgaria. The accelerograms obtained at the ground level or the basement of 1-2 storey buildings were considered to be free field records. The accelerograms recorded with instruments installed at the basement of mid-rise and tall buildings (3÷12 storeys) were not used. The epicentral distance of data goes up to 300km. In the majority of cases the records were obtained at soil sites. The distribution of the recorded accelerograms is given in Table 2.

Table 2. Distribution of the free field accelerograms used in the attenuation analysis

Seismic network	Romania			Republic of Moldova	Bulgaria	Total
Earthquake	*INCERC*[1)]	*INFP*[2)]	*GEOTEC*[3)]	*IGG*[4)]		
March 4, 1977	1	-	-	-	-	1
Aug. 30, 1986	24	8	3	2	-	37
May 30, 1990	23	10	2	2	5	42
Total	48	18	5	4	5	80

[1)] *INCERC, National Building Research Institute, Bucharest*
[2)] *INFP, National Institute for Earth Physics, Bucharest-Magurele*
[3)] *GEOTEC, Institute for Geotechnical and Geophysical Studies, Bucharest*
[4)] *IGG, Institute of Geophysics and Geology, Moldavian Academy of Science, Chisinau*

The maximum of the two horizontal components of the ground motions was considered for *PGA* attenuation. The distributions of maximum PGA with with epicentral distance and corresponding earthquake magnitudes are presented in Figure 3 and Figure 4.

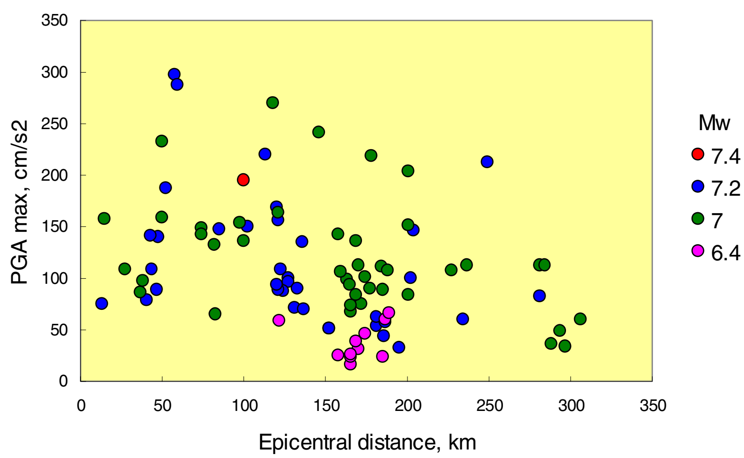

Figure 3. Distribution of *PGA* with epicentral distance and magnitude for Vrancea source

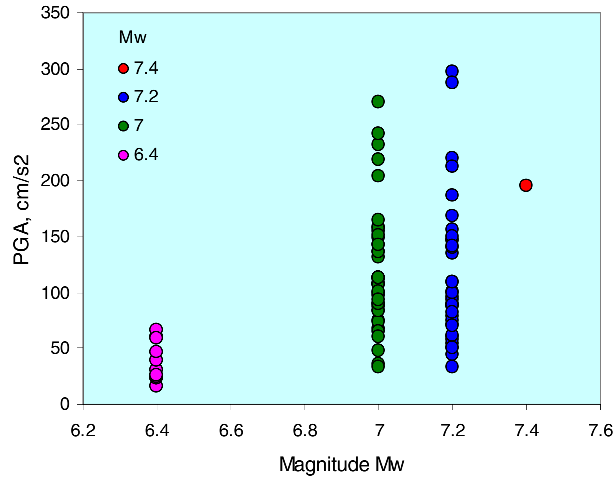

Figure 4. Distribution of *PGA* with magnitude for Vrancea source

The following attenuation model was selected for the attenuation analysis:

$$ln\ PGA = c_0 + c_1 M_w + c_2\ lnR + c_3 R + c_4\ h + \varepsilon \qquad (4)$$

where:

PGA is peak ground acceleration at the site,
M_w- moment magnitude,
R - hypocentral distance to the site $R = \sqrt{h^2 + \Delta^2}$,
h - focal depth,
c_0, c_1, c_2, c_3, c_4 - data dependent coefficients and
ε - random variable with zero mean and standard deviation $\sigma_\varepsilon = \sigma_{ln\ PGA}$.

The extrapolation of data in the range of large magnitudes ($M_w \geq 7.5$) is entirely based on the peak ground acceleration recorded in Bucharest during 1977 event. The coefficients obtained from the regression are given in Table 3 (Lungu *et al*. [16]).

Table 3. Regression coefficients for horizontal peak ground acceleration

	c_0	c_1	c_2	c_3	c_4	σ_{lnPGA}
All data	3.098	1.053	-1.000	-0.0005	-0.006	0.502

The attenuation relation from Eq. (4) can be used to predict the 84 percentile of horizontal *PGA*, produced by a magnitude having specified recurrence interval and an associated focal depth (Eq.3 with $P=1.0$).

Prediction of the peak parameters of the ground motion in Bucharest

For the city of Bucharest the use of Eq. 4 is illustrated in Figure 5. The experienced epicentral distance for Bucharest is $\Delta = 135 \pm 30\ km$. Figure 5 also presents the *PGA* values obtained using the P100-92 (code in force) requirements (*MRI= 50 & 100 yr*) and using the EUROCODE 8 reccomendation (*MRI=475yr.*).

M_w / h, km	M_w = 7.3 T = 50 yr.	M_w = 7.6 T = 100 yr.	M_w = 7.9 - 8.0 T = 475 yr.
90	264	343	580
100	231	328	526
110	**217**	**295**	477
120	**196**	**284**	**432**
130	177	**256**	**390**
140	160	208	353
150	145	188	319
	0.2g	0.3g ↕ 0.25g	0.45g ↕ 0.35g
	P100-92 code requirements for general buildings and structures	*P100-92* code requirements for essential facilities	**EUROCODE 8** requirements

Figure 5. Prediction of peak ground acceleration *PGA* in Bucharest (Δ=135 km)

ZONATION MAPS

In Figure 6 (Lungu et al. [21]) is illustrated the present seismic zonation of Romania, Republic of Moldova, Bulgaria and Ukraine. The general pattern (which is based on deterministic macroseismic observations) as well as the content of the Table 4 describing the conversion of seismic intensity into peak ground acceleration are self-explanatory. They clearly suggest the need for regional harmonization of seismic macrozonation maps and prove the need for a joint zonation of the seismic hazard in the influence area of the Vrancea source.

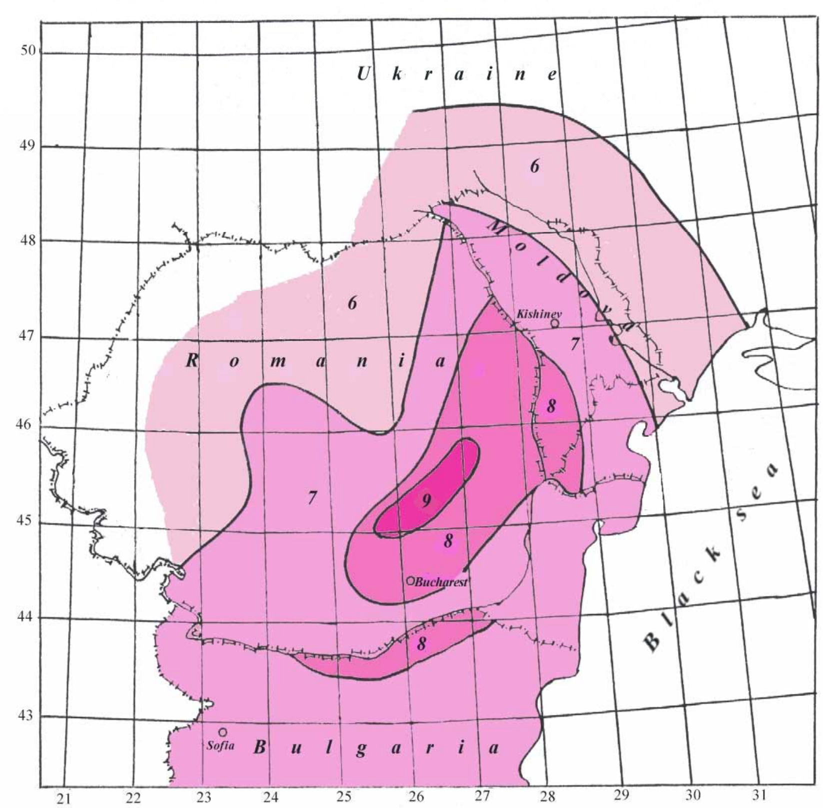

Figure 6. Seismic zonation maps for countries affected by Vrancea earthquakes

Table 4. Conversion of MSK seismic intensity into PGA in Romania, Rep. of Moldova and Bulgaria

MSK Intensity	PGA/g		
	ROMANIA P100-92& SR 11100/1-93	Rep. of MOLDOVA, UKRAINE SNIP II-7-81	BULGARIA 1987 code
IX	0.32	0.40	0.27
VIII	0.25 0.20	0.20	0.15
VII	0.16	0.10	0.10
V	0.12 0.08	-	0.05

It is emphasized that the present seismic code of Romania, P100-92, defines the earthquake hazard with 50 yr. mean recurrence interval (i.e., 63% exceedance probability in 50 yr). However, the American code ASCE 7-95/98, [22] and EUROCODE 8 [1] recommend a mean recurrence interval of 475 yr. (i.e., 10% exceedance probability in 50 years).

Based on the results of seismic hazard assessment from Vrancea source and taking into account the macroseismic fields from the crustal seismic sources around Romania, in Figure 7 is presented the proposed seismic hazard map for the P100-2003 proposal of earthquake resistant design code. The map presents the design ground acceleration for an event with mean recurrence interval *MRI=100 years*, that represents a transition value towards a more conservative hazard map (with *MRI=475years*).

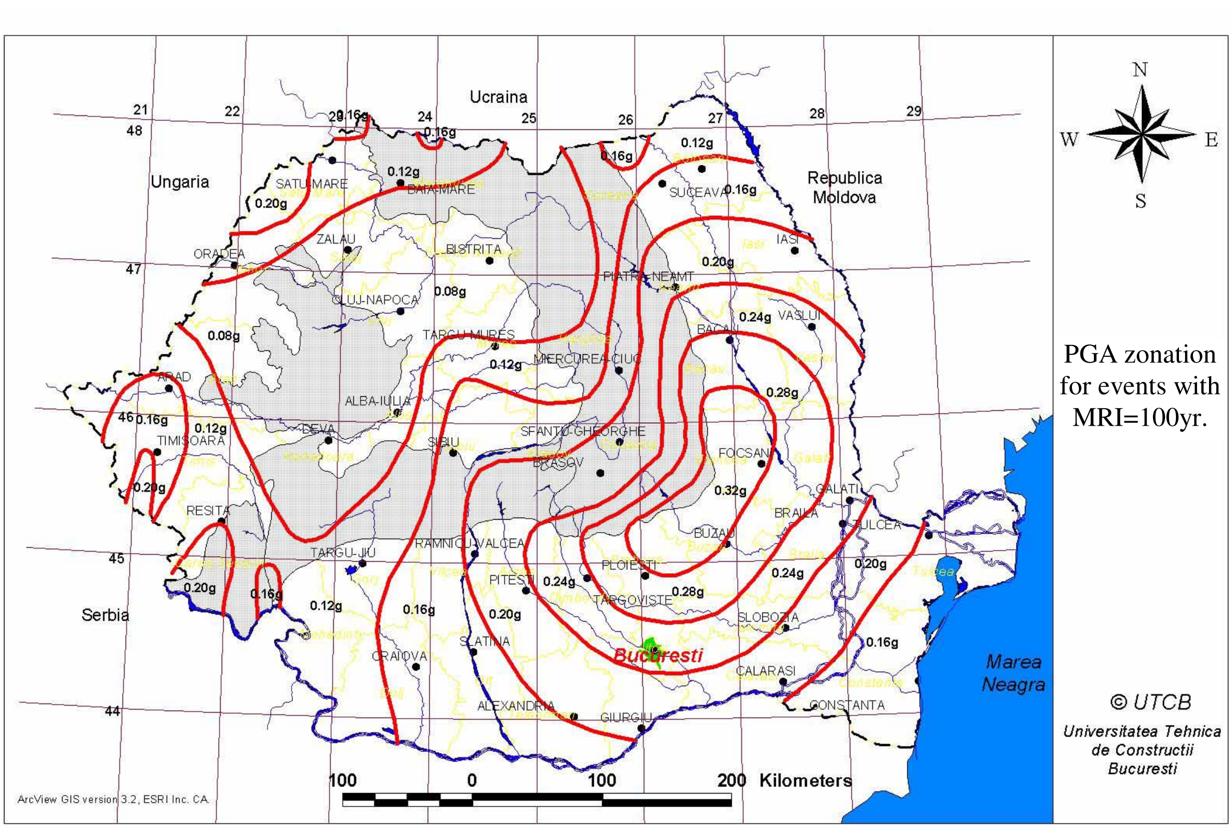

Figure 7. The design ground acceleration for an event with *MRI*=100 years.

In the actual code P100-92, as well as in the P100-2003 proposal, the ground conditions are characterized indirectly by the control period of response spectra *Tc*.
A direct characterisation/classification of ground conditions based on soil data (soil profile and shear velocities profile) is, unfortunately, not yet possible due to the lack of sufficient soil data correlated with recorded ground motions. The few cases where such information exists (i.e., soil data and earthquake records) showed that importing criteria and corresponding design spectra from other countries is not recommended, especially in the area under the influence of Vrancea source and where deep sediment deposits exists (Aldea [23]).
As an example, for the Bucharest INCERC record from 1977 earthquake, obtained at a site where the upper geology is characterized by shear wave velocities around 300m/s, the ground motion was characterized by a long predominant period and it's acceleration response spectra displayed high amplifications at long periods (1.4-1.6s).

The studies made on the complete data base of strong motion accelerograms of Romania showed that the control period of response spectra T_C is a reliable and stable indicator for characterizing the frequency content of ground motions, and indirectly the ground conditions. The T_C zonation for the P100-2003 proposal is presented in Figure 8, based on processed ground motion records and GIS technology.

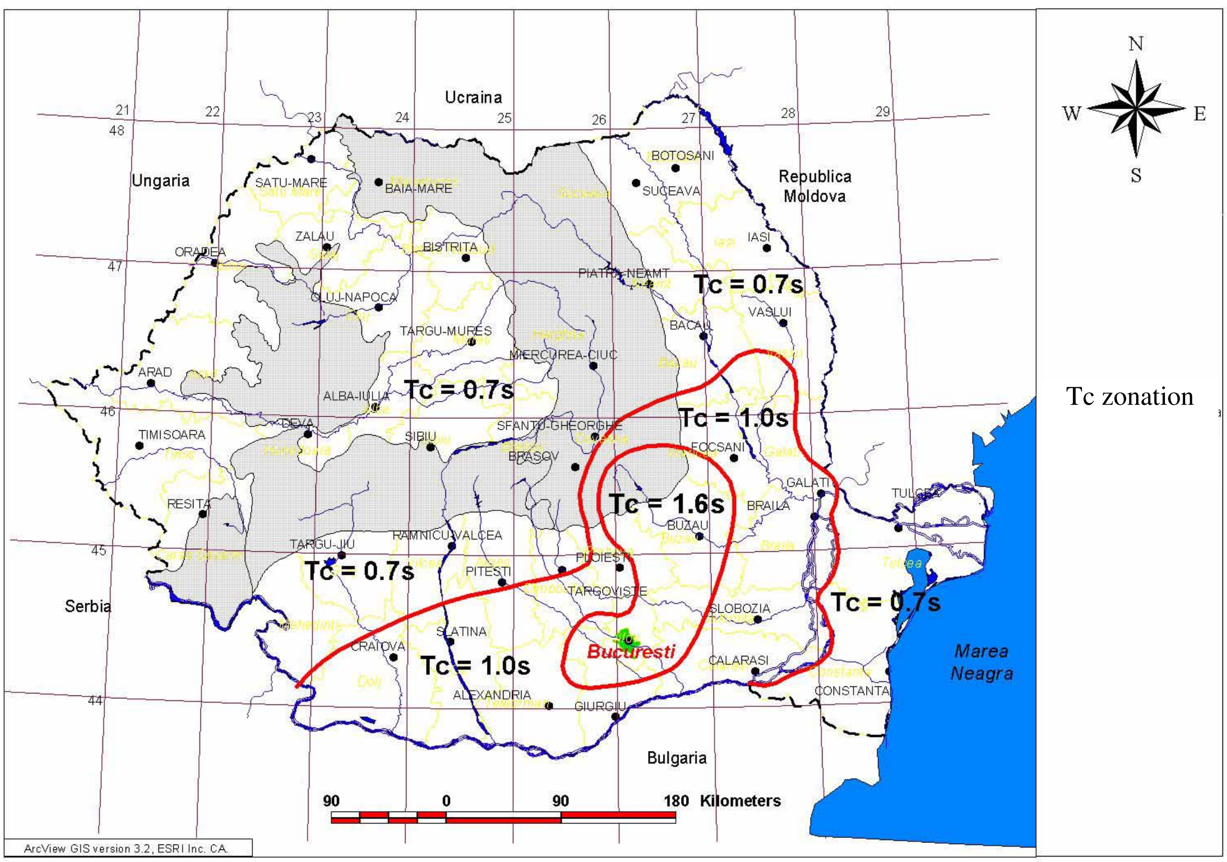

Figure 8. Zonation of control period of response spectra, T_C

DESIGN SPECTRA

For each of the three zones in Figure 8, a normalised acceleration response spectrum is recommended in the P100-2003 code proposal.

The normalised acceleration response spectrum $\beta(T)$ for the horizontal ground motion and for 5% damping, is following the EUROCODE 8 format, and is given by the following equations:

$T \le T_B$ $$\beta(T) = 1 + \frac{(\beta_0 - 1)}{T_B} T \qquad (5)$$

$T_B < T \le T_C$ $$\beta(T) = \beta_0 \qquad (6)$$

$T_C < T \le T_D$ $$\beta(T) = \beta_0 \frac{T_C}{T} \qquad (7)$$

$T > T_D$ $$\beta(T) = \beta_0 \frac{T_C T_D}{T^2} \qquad (8)$$

where:

$\beta(T)$ – normalised acceleration response spectrum (elastic);
β_0 – maximum dynamic amplification factor;
T – fundamental period of vibration of a single degree of freedom structure.

The control periods of response spectra T_B, T_C, T_D are given in Table 5.

Table 5. Control periods of response spectra T_B, T_C, T_D for horizontal ground motion

Control periods of response spectra			
T_B, s	0,07	0,10	0,16
T_C, s	0,7	1,0	1,6
T_D, s	3	3	2

The normalised acceleration response spectra for the three zones characterised by $Tc = 0.7s$, $Tc = 1.0s$ and $Tc = 1.6s$ are presented in Figure 9.

The elastic response spectra for horizontal ground motion is defined as:

$$S_e(T) = a_g \beta(T) \qquad (9)$$

The acceleration design spectra $S_d(T)$ is an inelastic response spectra obtained with the following relations:

$0 < T \le T_B$ $$S_d(T) = a_g \left[1 + \frac{\frac{\beta_0}{q} - 1}{T_B} T \right] \qquad (10)$$

$T > T_B$ $$= a_g \frac{\beta(T)}{q}. \qquad (11)$$

where

$S_d(T)$ - in m/s^2.
T – period, in sec.
q – behavior factor.

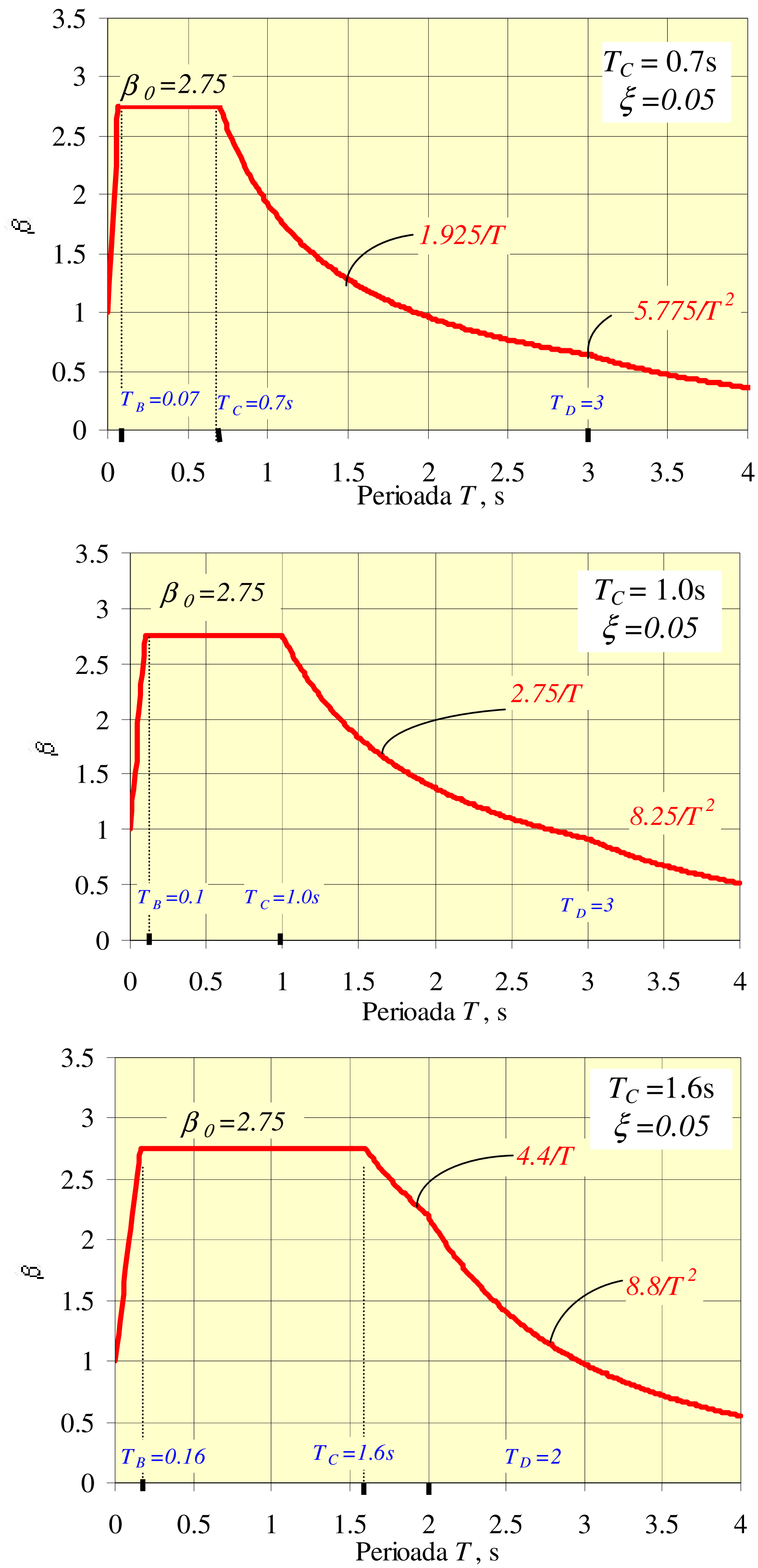

Figure 9. Normalised acceleration response spectra for horizontal ground motion in zones characterised by control periods *Tc = 0.7s, Tc = 1.0s* and *Tc = 1.6s*, in the P100-2003 code proposal

The behaviour factor *q* is given in the P100-2003 code proposal following EUROCODE 8 recommendations, for different types of materials and structural systems.

The seismic action quantified by the above design spectra is for ultimate limit state design.

The P100-2003 code proposal was developed at Technical University of Civil Engineering, Bucharest in 2003 within a contract with the Ministry of Transports, Constructions and Tourism, and will be published in 2004 for offering to the Romanian professional and scientific community a base for discussions, analysis and improvements, in a format that follows the EUROCODE 8.

CONCLUSIONS

The actual description of seismic action in Romanian P100-92 design code must be modified toward the requirements of the EUROCODE 8. The seismic zonation should be done using instrumental data and probabilistic seismic hazard assessment. The design spectra should correspond to different ground categories. The present proposal for modification uses a transition value of *MRI=100years* instead of *MRI=475years* required be EUROCODE 8 for the *PGA* zonation, and, due to the lack of ground data, it includes design spectra for regions characterized by different control (corner) period of response spectra T_C. The P100-2003 code proposal follows EUROCODE 8 requirements.

Acknowledgement

The ground motion data were provided by the late Dr. C. Radu, INFP, by Mr. S.Borcia INCERC-Bucharest and Dr. T. Moldoveanu, GEOTEC. We are indebted to all of them. The authors acknowledge with thanks the generous access to ArcView Spatial Analyst, ESRI Inc., provided by Mr. C. Vasile from GEOSYSTEMS, Romania. The support of JICA Project [6] for the research on seismic hazard assessment in Romania is also acknowledged.

REFERENCES

1. EUROCODE 8: Design of structures for earthquake resistance Part 1: General rules, seismic actions and rules for buildings, Draft No 5, Revised Final Project Team Draft (preStage 49), 2002
2. Bolt, B., (1995), Earthquakes, W. H. Freeman and Company, New York, 331p.
3. Coburn, A., Spence, R., (1992), "Earthquake protection", John Wiley & Sons., New York, 355p.
4. World Bank Report No. P-2240-RO, 1978. Earthquake in Romania, March 4, 1977
5. Building Research Institute, Ministry of Construction, Japan(1978) Digitized data of strong-motion earthquake accelerograms in Romania (March 4, 1977) by Observational Committee of Strong Motion Earthquake, Kenchiku Kenkyu Shiro No.20, January.
6. JICA Technical Cooperation Project "Reduction of Seismic Risk for Buildings and Structures" with Romania, 2002-2007, Ref.#7241011E0
7. Aldea, A., Lungu, D., Vacareanu, R., Arion, C., 2004. Development of strong ground motion network in Romania and Bucharest instrumentation for site effects assessment. Proceedings of 13 WCEE World Conference on Earthquake Engineering, CD-ROM, Vancouver, Canada
8. Radu, C. manuscripts, (1994). Catalogues of earthquakes occurred on Romanian territory during the periods 984-1990 and 1901-1994.
9. Constantinescu, L., Marza, V.I., (1980) A computer-compiled and computer-oriented catalogue of Romania’s earthquakes during a millennium. Revue Roumaine de Géologie, Géophysique et Géographie. Tome 24, No2, Editura Academiei R.S.Romania, p.193-206.

10. Marza, V., 1995. Romania's seismicity file: 1. Pre-Instrumental data. Special Publications of the Geological Society of Greece
11. Lungu, D., Arion, C., Aldea, A., Demetriu, S., (1999), "Assessment of seismic hazard in Romania based on 25 years of strong ground motion instrumentation", NATO ARW Conference on strong motion instrumentation for civil engineering structures, Istanbul, Turkey, June 2-5, 1999.
12. Lungu, D., Cornea, T., Aldea, A., Zaicenco, A., (1997). Basic representation of seismic action. In: Design of structures in seismic zones: Eurocode 8 - Worked examples. TEMPUS PHARE CM Project 01198: Implementing of structural Eurocodes in Romanian civil engineering standards. Edited by D.Lungu, F.Mazzolani and S.Savidis.Bridgeman Ltd., Timisoara, p.1-60.
13. Elnashai, A., Lungu, D., (1995). Zonation as a tool for retrofit and design of new facilities. Report of the Session A.1.2. 5th International Conference on Seismic Zonation, Nice, France, Oct. 16-19, Proceedings Vol.3, Ouest Editions, Preses Academiques, p.2057-2082.
14. Wells, D.L., Coppersmith, K.J., (1994). New empirical relations among magnitude, rupture length, rupture width, rupture area, and surface displacement. Bulletin of the Seismological Society of America, Vol.84, No 4, p. 974-1002.
15. Sandulescu, M., & Dinu, C., 1997. Contract between Technical University of Civil Engineering Bucharest, University of Bucharest and GEOTEC, No.178a
16. Lungu, D., Aldea, A., Arion, C., Demetriu, S., Cornea, T., 2000. Microzonage Sismique de la ville de Bucarest - Roumanie, Cahier Technique de l'Association Française du Génie Parasismique, No.20, p.31-63
17. Lungu, D., Cornea, T., Craifaleanu, I., Aldea, A., 1995. Seismic zonation of Romania based on uniform hazard response ordinates. 5th International Conference on Seismic Zonation, Nice, France, Oct.16-19. Proceedings Vol.1, p.445-452, Quest Editions, Presses Academiques, Nantes
18. Lungu, D., Demetriu, S., Aldea, A., Cornea, T., Craifaleanu, I., 1994. Uniform hazard response spectra in soft soil condition and EUROCODE 8, Scientific Bulletin of Technical University of Civil Engineering Bucharest, Vol.2/1994, p.45-56
19. Lungu, D., Cornea, T., Aldea, A., Zaicenco, A., 1997. Basic representation of seismic action. In: Design of structures in seismic zones: Eurocode 8 - Worked examples. TEMPUS PHARE CM Project 01198: Implementing of structural Eurocodes in Romanian civil engineering standards. Edited by D.Lungu, F.Mazzolani and S.Savidis. Bridgeman Ltd., Timisoara, p.1-60.
20. Lungu, D., Arion, C., Aldea, A., Demetriu, S., 1999. Assessment of seismic hazard in Romania based on 25 years of strong ground motion instrumentation, NATO ARW Conference on strong motion instrumentation for civil engineering structures, Istanbul, Turkey, June 2-5, 1999, 12p.
21. Lungu, D., Aldea, A., Demetriu, S., Craifaleanu, I., 2003."Seismic strengthening of buildings and Seismic instrumentation-Two priorities for seismic risk reduction in Romania".International Conference "Science and Technology for Safe Development of Lifeline Systems- Natural Risks: Developments, Tools and Techniques in the CEI Area", Sofia, Bulgaria, 24p.
22. ASCE 7-98, 2000. ASCE Standard: Minimum design loads for buildings and other structures. Revision of ANSI/ASCE 7-95. American Society of Civil Engineers, New-York, 330p.
23. Aldea, A., (2002). "Vrancea source seismic hazard assessment and site effects", PhD thesis Technical University of Civil Engineering Bucharest, Bucharest, 256p.