3. SEISMIC ACTION

3.1. Representation of the seismic action for design

(1) In case of seismic action for the design of buildings, the Romanian territory is divided in seismic hazard zones. The seismic hazard level in every zone is considered, in a simplified way, to be constant. It is recommended, for important urban centers and for buildings of particular importance, to resort to the local assessment of the seismic hazard, on the basis of the instrumental seismic data and of the specific studies regarding the site under consideration. The seismic hazard level indicated in the present code is a minimum design level.

(2) The seismic design hazard is described by means of the value of the peak horizontal ground acceleration a_g, determined for the mean recurrence (MRI) corresponding to the ultimate limit state, a value which is hereinafter referred to as "the design ground acceleration".

(3) The design ground acceleration, for every seismic hazard zone, corresponds to a reference mean recurrence interval of 100 years. The zonation of the design ground acceleration a_g in Romania, for seismic events having the mean recurrence interval (of the magnitude) $MRI = 100$ years, is indicated in the Figure 3.1 and is used for the design of buildings at the ultimate limit state.

(4) The seismic movement in a point on the surface of the ground is described by the elastic response spectrum for absolute accelerations.

(5) The horizontal seismic action on buildings is described by two orthogonal components considered to be independent from one another; the design elastic response spectrum for absolute accelerations is considered to be the same for the two components.

(6) The normalized elastic response spectra for accelerations are obtained from the elastic response spectra for accelerations, by dividing the spectral ordinates by the value of the peak ground acceleration a_g.

(7) The local ground conditions are described by the values of the control period (corner period) T_C of the response spectrum for the zone of the site under consideration. These values characterize in a synthetic way the frequency content of the seismic movements.

The control period (corner period) T_C of the response spectrum represents the border between the zone (level) of maximum values in the spectrum for absolute accelerations and the zone (level) of maximum values in the spectrum for relative velocities (see Annex A). T_C is indicated in seconds.

Taking into account both the seismic and the ground conditions existing in Romania, for earthquakes having $MRI = 100$ years, the design zonation of the Romanian territory in terms of control period (corner period) T_C of the response spectrum, obtained on the basis of the existing instrumental data for the horizontal components of the seismic movement, is presented in the Figure 3.2.

(8) The normalized forms of the elastic response spectra for the horizontal components of the ground acceleration $\beta(T)$, for the viscous damping ratio of $\xi = 0.05$ and on the basis of the control periods (corner periods) T_B, T_C and T_D, are the following:

$$0 \leq T \leq T_B \qquad \beta(T) = 1 + \frac{(\beta_0 - 1)}{T_B} T \qquad (3.2)$$

$$T_B < T \leq T_C \qquad \beta(T) = \beta_0 \qquad (3.3)$$

3.1

$$T_C < T \le T_D \qquad\qquad \beta(T) = \beta_0 \frac{T_C}{T} \qquad\qquad\qquad (3.4)$$

$$T > T_D \qquad\qquad \beta(T) = \beta_0 \frac{T_C T_D}{T^2} \qquad\qquad\qquad (3.5)$$

where:

$\beta(T)$ the normalized elastic response spectrum;

β_0 the factor of maximum dynamic amplification of the horizontal ground acceleration by the structure;

T vibration period of a linear single-degree-of-freedom system.

The control period (corner) T_B can be expressed, in a simplified way, on the basis of T_C: $T_B = 0.1T_C$. The values T_B are indicated in the Table 3.1.

The control period (corner period) T_D of the response spectrum represents the frontier between the zone (level) of maximum values in the spectrum for relative velocities and the zone (level) of maximum values in the spectrum for relative displacements (see Annex A). The values T_D are indicated in the Table 3.1.

T_B and T_C are the limits of the period domain in which the spectral acceleration reaches its maximum values and is modelled in a simplified way by means of a level whose value is constant.

Table 3.1 The control periods (corner seismic periods) T_B, T_C, T_D of the response spectrum for the horizontal components of the seismic movement:

Mean recurrence interval of the earthquake magnitude	Values of the control periods (corner periods)		
MRI = 100 years, For the ultimate limit state	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 normalized elastic response *spectra* (ξ=0.05) for acceleration, for the seismic and the ground conditions existing in Romania, are represented in the Figure 3.3, on the basis of the values T_B, T_C and T_D specified in the Table 3.1.
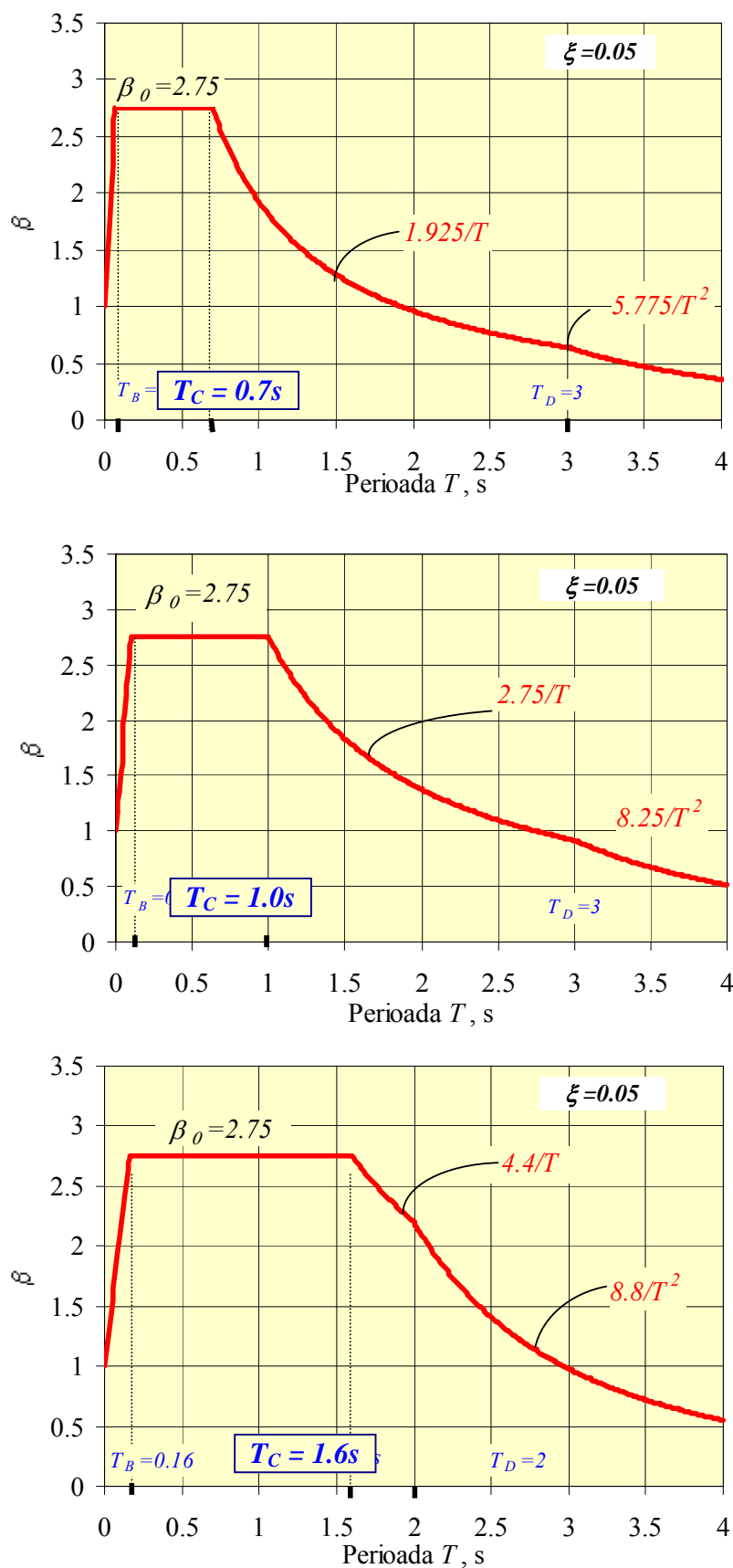
The normalized elastic response spectrum for acceleration presented in the Figure 3.4 is used in Banat, in the zones which are characterized by the acceleration $a_g = 0.20g$ and $a_g = 0.16g$. For the zones of Banat where $a_g = 0.12g$ and $a_g = 0.08g$, the normalized spectrum in the Figure 3.3 for $T_C \le 0.7s$ is used.

3.2
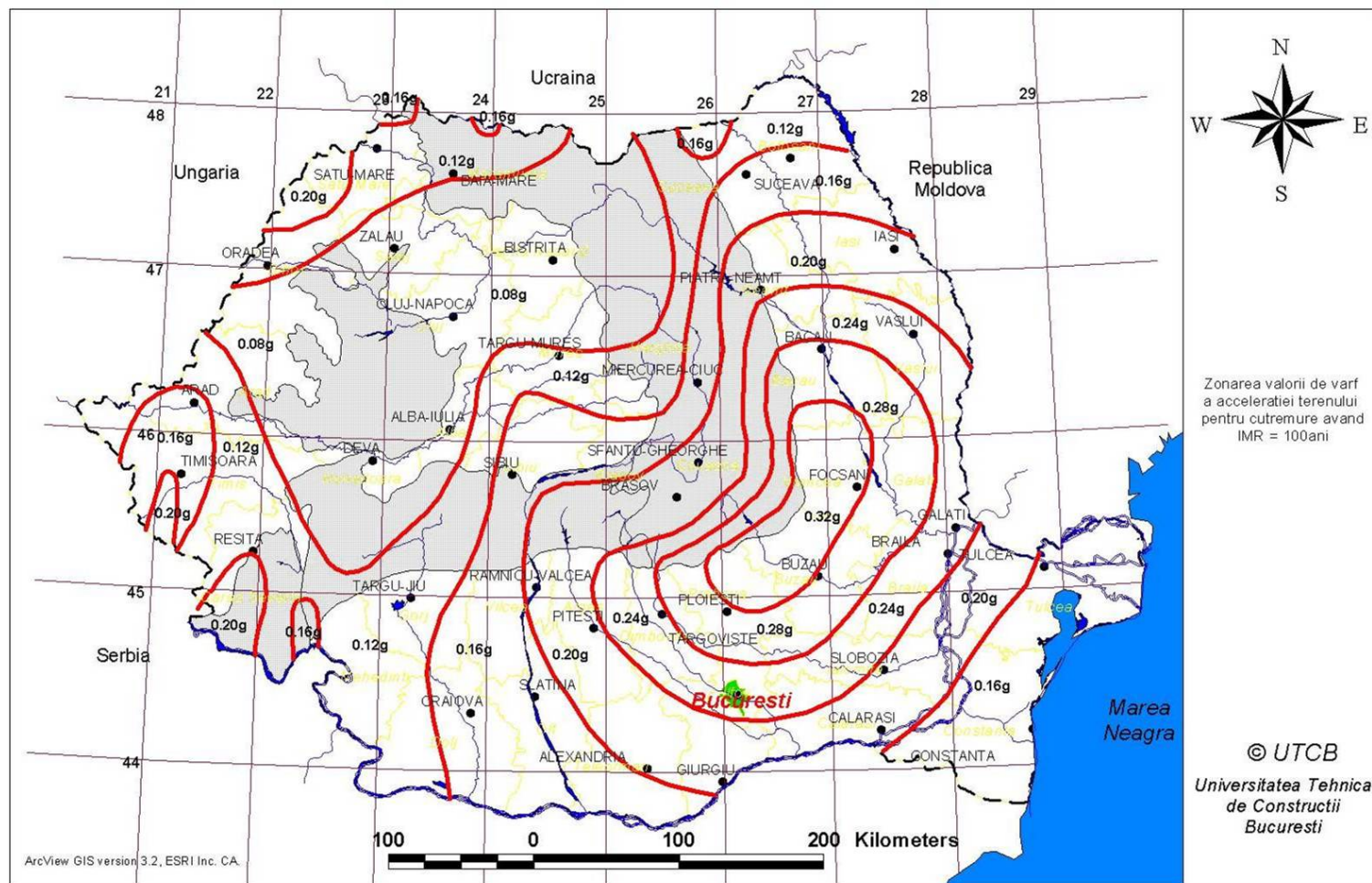
Figure 3.1 Zonation of the Romanian territory in terms of values of the peak design ground acceleration a_g for earthquakes having the mean recurrence interval $MRI = 100$ years
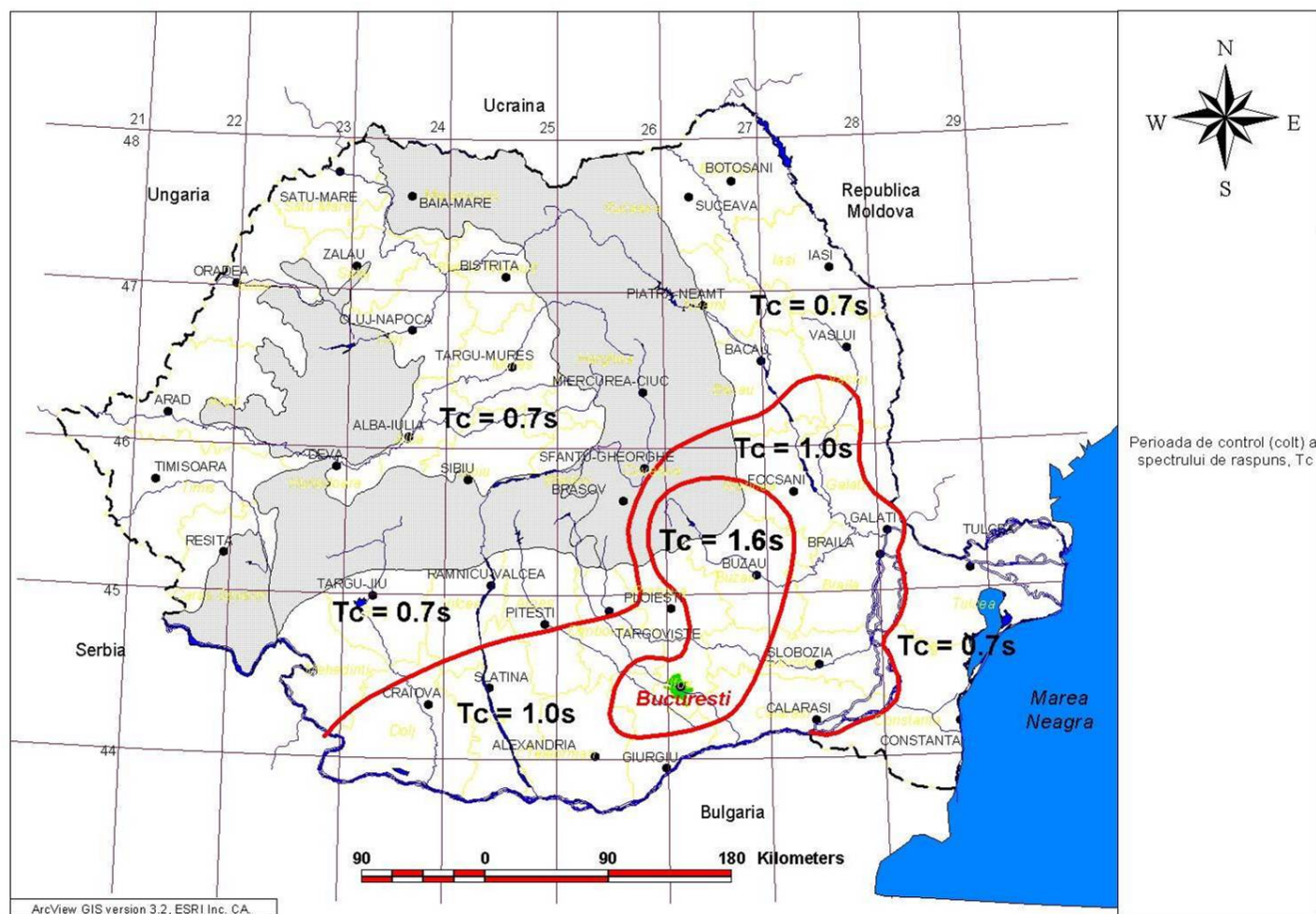
3.3

Figure 3.2 Zonation of the Romanian territory in terms of control period (corner period) T_C of the response spectrum

3.4

Figure 3.3 Normalized elastic response spectra for accelerations for the horizontal components of the ground movement, in the zones which are characterized by the control periods (corner periods): $T_C = 0.7$, $T_C = 1.0$ and $T_C = 1.6$s.

3.5
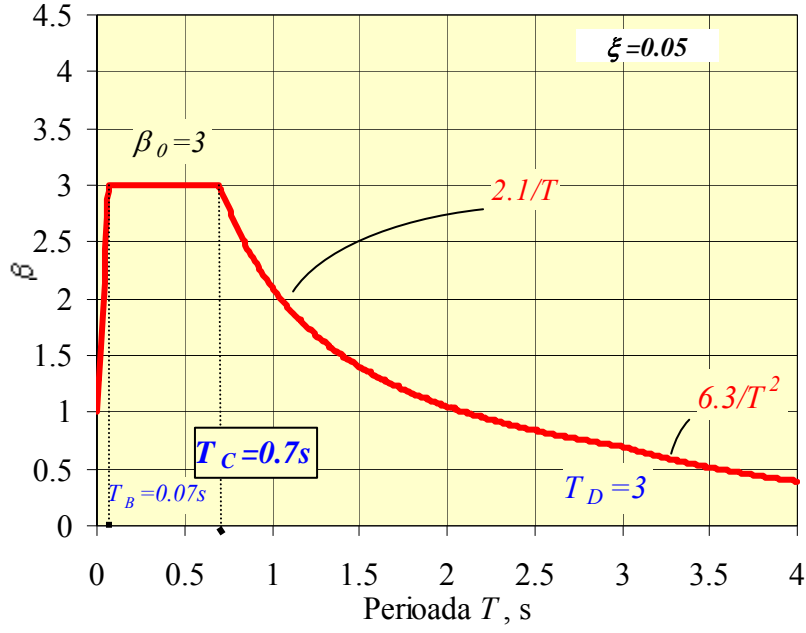
Figure 3.4 Crustal sources in Banat: normalized elastic response spectrum for accelerations for the horizontal components of the ground movement, for the zones where the seismic hazard is characterized by $a_g = 0.20g$ and $a_g = 0.16g$.

The elastic response spectrum for the horizontal components of the ground acceleration on site $S_e(T)$, expressed in m/s², is defined as follows:

$$S_e(T) = a_g \beta(T) \tag{3.6}$$

where the value a_g is considered in m/s².

The elastic displacement response spectrum for the horizontal components of the ground movement, $S_{De}(T)$, expressed in m, is obtained by directly transforming the elastic acceleration response spectra $S_e(T)$, using the following expression:

$$S_{De}(T) = S_e(T) \left[\frac{T}{2\pi} \right]^2 \tag{3.7}$$

(9)   The vertical component of the seismic action is represented by means of the elastic response spectrum for accelerations for the vertical component of the ground movement. The normalized forms of the elastic response spectra for the vertical component $\beta_v(T)$, for the fraction of the critical amortization $\xi = 0.05$ and on the basis of the control periods (corner seismic periods) for the spectrum of the vertical component T_{Bv}, T_{Cv}, T_{Dv}, are described by means of the following relations:

$$0 \leq T \leq T_{Bv} \qquad \beta_v(T) = 1 + \frac{(\beta_{0v} - 1)}{T_{Bv}} T \tag{3.8}$$

$$T_{Bv} < T \leq T_{Cv} \qquad \beta_v(T) = \beta_{0v} \tag{3.9}$$

3.6

44-9

$$T_{Cv} < T \leq T_{Dv} \qquad \beta_v(T) = \beta_{0v} \frac{T_{Cv}}{T} \qquad\qquad (3.10)$$

$$T > T_{Dv} \qquad \beta_v(T) = \beta_{0v} \frac{T_{Cv} T_{Dv}}{T^2} \qquad\qquad (3.11)$$

where $\beta_{ov} = 3.0$ is the factor of maximum dynamic amplification of the vertical acceleration of the ground movement by the structure, having the ratio of critical damping $\xi=0.05$.

The control periods (corner periods) of the normalized response spectra for the vertical component of the seismic movement are considered, in a simplified way, to be the following:

$$T_{Bv} = 0.1\ T_{Cv} \qquad\qquad (3.12)$$

$$T_{Cv} = 0.45\ T_C \qquad\qquad (3.13)$$

$$T_{Dv} = T_D. \qquad\qquad (3.14)$$

The elastic response spectrum for the vertical component of the ground movement on site S_{ve} is defined as follows:

$$S_{ve}(T) = a_{vg}\beta_v(T). \qquad\qquad (3.15)$$

The value of the peak acceleration for the vertical component of the ground movement a_{vg} is assessed as being:

$$a_{vg} = 0.7\ a_g. \qquad\qquad (3.16)$$

(10)   In Bucharest, is a very clear instrumental evidence concerning the long predominant period ($T_p=1.4\div1.6$s) of the ground vibration during the Vrancea moderate and high magnitudes earthquakes (Gutenberg-Richter magnitude $M \geq 7.0$; moment magnitude $M_w \geq 7.2$).

The definition of the predominant period of the ground vibration is given in the Annex A.

The design of structures having an period of vibration similar with the predominant period of the ground vibration must be avoided.

3.1.1. Alternative representations of the seismic action

In the dynamic calculation of structures, the seismic movement is described by means of the variation in time of the ground acceleration (accelerogram).

When a model of spatial calculation is necessary, the seismic movement must be characterized by means of three simultaneous accelerograms corresponding to the three orthogonal directions (two horizontal and one vertical). Different accelerograms are simultaneously used along the two horizontal directions.

3.7

3.1.2. Artificial accelerograms

The artificial accelerograms are those accelerograms which are generated on the basis of an elastic response spectrum for accelerations on site, $S_e(T)$.

The elastic response spectrum of the artificial accelerograms must be close to the elastic response spectrum for accelerations on site.

On the basis of the elastic response spectrum for accelerations on site $S_e(T)$, a set of artificial accelerograms must be generated, which fulfill the following conditions:

   a) The minimum number of accelerograms must be 3 (three);

   b) The arithmetic mean of the values of the peak accelerations of the generated accelerograms must be higher than the value a_g of the respective site;

   c) All the values of the medium spectrum, calculated by means of the arithmetic mean of the ordinates of the elastic response spectra for accelerations corresponding to all the generated artificial accelerograms, must be with minimum 10% higher than the corresponding value of the elastic response spectrum on site $S_e(T)$.

3.1.3. Recorded accelerograms

The recorded accelerograms can be used if they are recorded in the proximity of the site concerned, provided that the maximum value of the recorded acceleration is scaled so as to be the same with the value a_g on site and the frequency content is compatible with the local ground conditions.

Recorded accelerograms on other sites can be also used in accordance with the following conditions: the maximum acceleration must be scaled; the characteristics of the seismic sources, the distance source-site and the ground conditions on site must be similar.

In all cases, at least 3 (three) accelerograms must be used.

All the values of the mean spectrum of the recorded accelerograms which shall be used, shall be with minimum 10% higher than the corresponding value of the elastic response spectrum on site $S_e(T)$.

3.1.4. Spatial model of the seismic action

For structures with special characteristics such that the assumption of the same excitation at all support points cannot be reasonably made, it is recommended to use the spatial models of the seismic action which take into account the variability of the ground movement from one point to another.

The compatibility between the response spectra of the accelerograms from different points and the elastic response spectrum for accelerations on site $S_e(T)$, which is recommended by the rules, must be checked, just like in the case of the artificial accelerograms.

3.2. Design spectrum

The acceleration design spectrum $S_d(T)$, expressed in m/s^2, is a non-elastic response spectrum which is obtained by means of the relations 3.17 and 3.18:

3.8

$$0 < T \le T_B \qquad S_d(T) = a_g \left[1 + \frac{\dfrac{\beta_0}{q} - 1}{T_B} T \right] \qquad (3.17)$$

$$T > T_B \qquad = a_g \frac{\beta(T)}{q} . \qquad (3.18)$$

where

q is the behaviour factor of the structure (the factor of modification of the elastic response into a non-elastic response), whose values depend on the type of structure and its capacity of energy dissipation.

The values of the behaviour factor q for different types of materials and structural systems are indicated in specific chapters of the present code.

The design spectrum for the vertical component of the seismic movement is obtained in a similar way. In this case, the value of the behaviour factor is considered, in a simplified way, to be 1.5 for all the materials and structural systems, except for the situations where higher values can be justified by means of special analyses.

3.3. Combination of the seismic action with other types of actions

As for the design of buildings placed in seismic zones in the ultimate limit state, the design value of the combined effects of the actions is determined by means of the groups of effects of the loadings in accordance with *CR0-2005*.

SEISMIC ACTION:
DEFINITIONS AND ADDITIONAL PROVISIONS

A.1 Definitions of control periods (corner periods) of response spectra

The values of the control periods (corner periods) of the response spectra, T_C and T_D, calculated according to the definitions listed in this chapter for the accelerograms recorded during moderate and strong earthquakes of Romania, have been used to draw up the map of Figure 3.2 – Zonation of the Romanian territory in terms of control period (corner period), T_C of the response spectrum, and to establish the values of Table 3.1.

The control periods (corner periods) of the response spectra, T_C and T_D, are defined as follows:

$$T_C = 2\pi \frac{EPV}{EPA} \qquad\qquad (A1.1)$$

$$T_D = 2\pi \frac{EPD}{EPV} \qquad\qquad (A1.2)$$

where EPA is the effective peak acceleration, EPV is the effective peak velocity and EPD is the effective peak displacement of the ground movement,

The control period (corner period) T_B is considered $T_B = 0.1 T_C$.

The definition of the parameters EPA, EPV and EPD – invariant to the frequency content of the seismic motions – is obtained by the averaging the response spectrum for absolute accelerations SA, the response spectrum for relative velocities SV and of the response spectrum for relative displacements SD on a period interval with reference width of 0.4 s. The average interval is mobile and it is positioned on the axis of periods where the maximum of the average of the spectral values is obtained, respectively:

$$EPA = \frac{(SA_{mediat\ pe\ 0,4s})max}{2,5} \qquad\qquad (A1.3)$$

$$EPV = \frac{(SV_{mediat\ pe\ 0,4s})max}{2,5} \qquad\qquad (A1.4)$$

$$EPD = \frac{(SD_{mediat\ pe\ 0,4s})max}{2,5} . \qquad\qquad (A1.5)$$

A.2 Predominant period (frequency) of ground vibrations

The predominant period (frequency) of ground vibrations is defined as the abscissa on the axis of periods (frequencies), which corresponds to the peak power spectral density of the ground acceleration measured for earthquakes of medium and high magnitude.

Within the ground conditions from the East, the South and a part of the center of Bucharest, for moderate and strong earthquakes of Vrancea (Gutenberg-Richter magnitude $M \geq 7.0$; moment magnitude $M_w \geq 7.2$), there is clear instrumental evidence concerning the long predominant period $T_p = 1.4 \div 1.6$s of ground vibrations, Figure A.1.
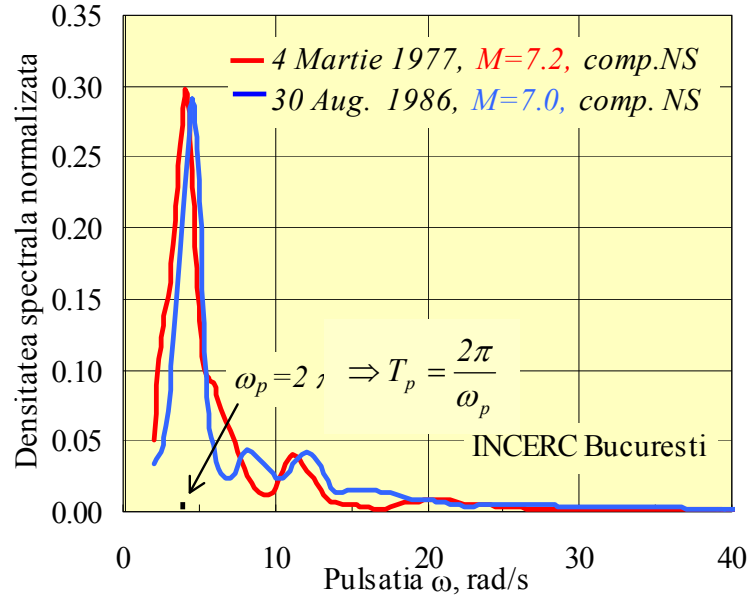
Figure A.1 The normalized power spectral density for the NS component of the earthquake records of March 4, 1977 and August 30, 1986 within INCERC station in the East of Bucharest

A.3 Seismic characterization of ground conditions

For buildings belonging to class 1 of importance-exposure, it is recommended to conduct studies for the seismic characterization of ground conditions on site. These studies must include:

(i) The profile of the velocity of the shear waves V_s and of the compression waves V_p, as from the ground surface to the base rock, but for a depth of minimum 30 meters from the ground surface when the base rock lies at high depth;

(ii) The stratigraphy of the site (the thickness and the type of ground for every layer) and the profile of the densities;

(iii) The profile of the velocities of the shear waves V_s is characterized by $\overline{V_S}$, representing the average velocity balanced with the thickness of the profile layers, as defined according to the relation A.3.1:

$$\overline{V_S} = \frac{\sum\limits_{i=1}^{n} h_i}{\sum\limits_{i=1}^{n} \dfrac{h_i}{V_i}} \qquad (A3.1)$$

where h_i and V_i are the thickness and respectively, the velocity of the shear waves for the layer i.

The parameter $\overline{V_S}$ is calculated for at least 30 meters of ground profile.

3.11

The estimation of the vibration period of the whole package of layers of h thickness considered on site, T_g, can be simplified by means of the following formula:

$$T_g = \frac{4h}{\overline{V_s}} \qquad\qquad (A3.2)$$

where h is the total thickness of the ground profile under consideration.

On the basis of the values of the balanced average velocity $\overline{V_S}$, the ground conditions can be classified into the following four classes:

Class A, rock-type ground	$\overline{V_S} \geq 760$ m/s,
Class B, hard ground	$360 < \overline{V_S} < 760$ m/s,
Class C, intermediary ground	$180 < \overline{V_S} \leq 360$ m/s,
Class D, soft ground	$\overline{V_S} \leq 180$ m/s.

In order to establish the elastic response spectra, which correspond to the ground class thus determined, the methodologies of the international practice shall be used.

A.4 Seismic instrumentation of buildings

In the seismic zones for which the value of the design acceleration $a_g \geq 0.24$g, the buildings of over 50 meters high or having more than 16 storeys or having a displayed surface of over 7500m^2 shall be instrumented with a digital acquisition system and minimum 3 (three) triaxial sensors for acceleration.

This minimal instrumentation shall be located as follows: 1 sensor on the floor of the last storey, as closer as possible to the center of the building, 1 sensor which monitors the ground movement and optionally, 1 sensor located in the depth drilling or in other position inside the building. The instruments shall be located so that the access to the devices is possible at any time.

The instrumentation, the maintenance and the exploitation are financed by the owner of the building. The records obtained during powerful earthquakes shall be made available to the competent authorities and specialized institutions.

A.5 Vrancea source. Zonation of the ground acceleration for *MRI (mean recurrence interval)* = 475 years

The zonation map of the maximum horizontal ground acceleration for *MRI*=475 years shall be introduced in the next issue of the code. Informatively, for Bucharest $a_{g,\ MRI=475years} = 0.36$g.

3.12

A.6 Table of macroseismic characteristics of the main cities of Romania (according to Fig.3.1 and Fig.3.2)

City/Town	T_C (sec)	a_g for MRI=100 years
Alba Iulia	0.7	0.08g
Alexandria	1.0	0.20g
Arad	0.7	0.16g
Bacău	0.7	0.28g
Baia Mare	0.7	0.12g
Bârlad	1.0	0.28g
Bistriţa Năsăud	0.7	0.08g
Botoşani	0.7	0.16g
Brăila	1.0	0.24g
Braşov	0.7	0.20g
Bucharest	1.6	0.24g
Buzău	1.6	0.28g
Călăraşi	1.0	0.20g
Câmpulung Moldovenesc	0.7	0.12g
Câmpulung Muscel	0.7	0.24g
Caracal	1.0	0.16g
Caransebeş	0.7	0.12g
Carei	0.7	0.20g
Cernavodă	1.0	0.16g
Cluj Napoca	0.7	0.08g
Constanţa	0.7	0.16g
Craiova	1.0	0.16g
Curtea de Argeş	0.7	0.20g
Dej	0.7	0.08g
Deva	0.7	0.08g
Dorohoi	0.7	0.12g
Drobeta Turnu Severin	0.7	0.12g
Făgăraş	0.7	0.16g
Fălticeni	0.7	0.16g
Feteşti	1.0	0.20g

3.13

City/Town	T_C (sec)	a_g for MRI=100 years
Focşani	1.0	0.32g
Galaţi	1.0	0.24g
Giurgiu	1.0	0.20g
Hunedoara	0.7	0.08g
Huşi	0.7	0.20g
Iaşi	0.7	0.20g
Lugoj	0.7	0.12g
Mangalia	0.7	0.16g
Medgidia	0.7	0.16g
Mediaş	0.7	0.16g
Miercurea Ciuc	0.7	0.16g
Odorheiu Secuiesc	0.7	0.12g
Oneşti	0.7	0.28g
Oradea	0.7	0.12g
Orăştie	0.7	0.08g
Orşova	0.7	0.16g
Paşcani	0.7	0.20g
Petroşani	0.7	0.12g
Piatra Neamţ	0.7	0.20g
Piteşti	0.7	0.20g
Ploieşti	1.0	0.28g
Rădăuţi	0.7	0.16g
Reghin	0.7	0.08g
Reşita	0.7	0.12g
Rm. Sărat	1.6	0.28g
Roman	0.7	0.24g
Roşiori de Vede	1.0	0.20g
Satu Mare	0.7	0.12g
Sfântu Gheorghe	0.7	0.20g
Sibiu	0.7	0.16g
Sighetu Marmaţiei	0.7	0.16g
Sighişoara	0.7	0.12g
Slatina	1.0	0.16g

3.14

City/Town	T_C (sec)	a_g for MRI=100 years
Slobozia	1.0	0.20g
Suceava	0.7	0.16g
Târgovişte	0.7	0.24g
Tecuci	1.0	0.28g
Tg. Jiu	0.7	0.12g
Tg. Mureş	0.7	0.12g
Timişoara	0.7	0.16g
Tulcea	0.7	0.16g
Turda	0.7	0.08g
Turnu Măgurele	1.0	0.16g
Urziceni	1.6	0.28g
Vaslui	0.7	0.24g
Zalău	0.7	0.08g

A.7 The elastic response spectrum for different ratio of critical damping

For the design situations for which it is necessary to use an elastic response spectrum for another ratio of critical damping than the conventional one of 5%, it is recommended to use the following relation of conversion of the spectral ordinates:

$$S_e(T)_{\xi \neq 5\%} = S_e(T)_{\xi_0 = 5\%} \cdot \eta \qquad (A.7.1)$$

where:

$S_e(T)_{\xi_0 = 5\%}$ - the elastic response spectrum for the ground acceleration components on site which corresponds to conventional ratio of critical damping, $\xi_0 = 5\%$

$S_e(T)_{\xi \neq 5\%}$ - the elastic response spectrum for the ground acceleration components on site which corresponds to other ratio of critical damping, $\xi \neq 5\%$

η – the correction factor, which takes into account the damping, determined by means of the following relation (A.7.2):

$$\eta = \sqrt{\frac{10}{5 + \xi}} \geq 0{,}55 \qquad (A.7.2).$$

3.15