SITE CONDITIONS AND PREDOMINANT PERIOD OF SEISMIC MOTION IN THE BUCHAREST URBAN AREA*

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Reconsideration of previous information and results allows us to investigate how near-surface geological units of Bucharest area play a role in determining ground motion response in period bands that are of engineering significance. The superficial deposits within the study area are entirely Quaternary. Lithological information has been compiled from geological, geotechnical and hydrogeological boreholes. The predominant periods of oscillation of the subsurface layers over Bucharest territory have calculated values between 0.9 and 1.9 s, increasing from south to north, in correlation with the constant increasing of the thickness of the Quaternary cohesionless deposits. They are accurately matching the results obtained by seismological studies using seismograms of Vrancea moderate-magnitude earthquakes, recorded at the Bucharest seismic station.

Key words: predominant period, cohesionless deposits, Bucharest, Vrancea subcrustal earthquakes.

1. INTRODUCTION

In the last century two destroying earthquakes hit Bucharest city, in November 10, 1940 (M_w = 7.7, h = 150 km) and March 4, 1977 (M_w = 7.4, h = 94 km). The November 1940 earthquake severely damaged many tall buildings and the new 13-storey reinforced-concrete Carlton hotel, sited in the central zone of the city, collapsed killing 267 people. During the earthquake of March 1977, which is considered the most destructive seismic event that hit the city in modern times, the largest damage affected the tall buildings, six to twelve storey high reinforced-concrete frame structures. These structures have the fundamental period of 0.7 to 1.6 s, which places them on the ascending branch of the Bucharest spectrum (Fig. 1). On the contrary, the rigid structures of large panel or frame construction with shear walls, of the same height, as well as masonry dwellings of one to three storeys, suffered relatively small damage (Ambraseys, 1978).

The strong contribution of the local response at seismic input in the long-period range has been known since the analysis of the first seismograms recorded at the Bucharest seismic station. A study carried out on the basis of more than one hundred seismograms of Vrancea moderate earthquakes recorded at the Bucharest

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seismic station between 1936 and 1963 (Radu, 1965) showed an average characteristic predominant period of the ground motion of 1.3 s.

The first attempt to evaluate the predominant period of motion by computation, taking into consideration the Quaternary deposit thickness and the average shear wave velocity, led to values in the interval 0.9–1.6 s (Mândrescu, 1978).

The recent researches developed within the National Institute for Earth Physics in Bucharest were designed to the better knowledge of the local geological conditions beneath the Bucharest area, on the one hand, and to collect, analyze and correlate the information related to the distribution of the shear wave velocity in these layers, on the other hand. The processing of these two types of information into GIS format allowed the completion of new maps (at the surface of Frăteşti and Uzunu complex layers). The main characteristics of these maps are reflected in the map of the predominant period distribution.

2. GEOMORPHOLOGY

Bucharest city is located in the Romanian Plain, a major relief unit, lying between the peri-Carpathians piedmonts to the north and west and the area of tablelands, hills and mountains of Dobruja to the south and east. Bucharest is sited in the central part of the Vlăsia Plain (Fig. 2), considered as a transition zone between the piedmont plains of the north and the Danubian plain of the south (Vâlsan, 1915; Mihăilescu, 1924). The Vlăsia Plain lies between the Prahova valley to the north and the Argeş–Dâmboviţa valleys to the south, and represents a continuation of the common alluvial fans of the Ialomiţa and Dâmboviţa rivers. This central morphological unit can be divided into two subunits: the Snagov plain to the north and the Bucharest plain to the south. The Bucharest plain hydrologically belongs to the two confluence basins, Dâmboviţa and Argeş. The Dâmboviţa valley is the morphohydrographical axis of this plain, bounded to the N–NE by the Otopeni plain, and to the S–SE by the Câlnău plain (Coteţ, 1976).

The valleys of the Colentina, Pasărea and Câlnău, tributaries of the Dâmboviţa, mark the interstream system Dâmboviţa–Sabar, Dâmboviţa–Colentina and Colentina–Mostiştea. These interstreams look like extended plains, more elevated than the meadows, slightly fragmented by narrow valleys and hollows. The system of valleys deeply crossing the plain in the Bucharest area has the character of longitudinal and parallel channels.

As concerns the topography, the elevation of the Bucharest zone above the sea level lies between 60 m and 95 m. The elevation contour lines are generally oriented NE–SW, roughly perpendicular to the direction of the two main valleys going across the city. The elevation is gradually decreasing, with minor fluctuation from NW to SE (Fig. 3); the average slope has similar values, 0.5–0.6 m/km, both in the interstream area and at the bottom of the valleys. The transverse slopes have large values, especially on the right bank, nearly reaching the vertical (Coteţ, 1963).

A few areas of local plains are distinct over the territory of the city, respectively *Băneasa–Pantelimon, Giuleşti–Floreasca, Vergului* and *Cotroceni–Văcăreşti*.

The Băneasa and Pantelimon plains, situated in the northern part of the city, are separated by a valley of erosion – Saula – supplied from ground water and rainwater.

In the interstream space Colentina–Dâmbovița, the Giuleşti–Floreasca plain is developed in the NW part, with heights between 85 and 95 m, and the Vergului plain in the S–SE part, with lower heights, 70 to 80 m, respectively. Three morphological steps are evidenced inside this interstream area, corresponding to pseudoterraces, created in a different manner than the typical fluviatile terraces (Coteț, 1963).

The interstreams are slightly slanting toward SE. The Dâmbovița–Colentina interstream is situated 10–15 m below the level of the Cotroceni–Văcăreşti plain, due to the sliding of the Dâmbovița River over its own alluvial fan towards its present-day course. This is evident in the extended terraces that display the form of fans identified inside this interstream.

The Cotroceni–Văcăreşti plain, located in the southern part of the city, expands on the right bank of the Dâmbovița river. It looks like a flat plain with heights between 85 and 95 m in the Cotroceni area and 80–85 m in the Văcăreşti area.

3. GEOLOGY

3.1. STRATIGRAPHY

Bucharest is sited in the central part of the Moesian (Walachian) platform, which corresponds, from a morphological point of view to the Romanian Plain, at around 165 km apart from the epicentral area of Vrancea.

The Moesian platform has a basement with two structural stages, a lower one with chloritic and sericitic schists of Precambrian age and an upper one made up of old Paleozoic folded marine formations going back to the Middle Carboniferous age. The sedimentary cover, relatively thick (exceeding 6,000 m), is the result of four major cycles of sedimentation: a) Paleozoic, b) Permian–Triassic, c) Jurassic–Cretaceous and d) Upper Miocene–Quaternary.

The first sedimentation cycle starts with mainly arenitic deposits, continues with argillites, intercalations of sandstones and limestones, then with a horizon of the Old Red Sandstone type, with partly lagoonal dolomites and limestones and terrigenous deposits. Within this succession, one can notice some sedimentary gaps, syncronous with the Taconian, Ardenian and Breton diastrophism.

The second sedimentation cycle starts with the Permian and ends with the Upper Triass. Accumulations of mainly terrigenous, quasi-continental deposits, associated with effusive magmatite took place during the Permian; siliceous sandstones with intercalations of clays and limestones, during the Lower Triass; limestones, dolomites, anhidrites and salt, during the Middle Triass, and again a sequence of mainly terrigenous deposits, during the Upper Triass.

The third sedimentation cycle starts in the Upper Lias and ends in the Senonian. The Upper Lias–Dogger interval is represented by terrigenous formations. Sandstones predominante at the base of this interval, and clays and more seldom marno-limestones in the rest of the profile. Accumulations of carbonatic, pelagic, neritic-reefal, lagoonal deposits took place from the Callovian till the Aptian. In the second part of the Cretaceous, the carbonatic character of the deposits is diminished by the accumulation of horizons of marno-limestones, marl and sandstones. The process of sedimentation was interrupted during the Meso-Cretaceous and locally, during the Callovian, Cenomanian and Senonian (Mutihac, Ionesi, 1974; Paraschiv, 1979).

The fourth sedimentation cycle starts in the Badenian and ends in the Quaternary. During this period, only terrigenous deposits accumulated.

The Badenian deposit represented by marls with clay, sands and gravels was noticed in the boreholes.

The Sarmatian transgressively settled down over the Badenian deposits. It is represented by all its terms. Two successions were encountered in boreholes, one basal, arenitic and an other in the upper part, consisting of sands, clays, sandy clays and compact marls.

The Meotian consists of predominant detrital deposits with thickness of a few meters in the south, down to 600–700 m in the north. Borehole data allowed the separation of two lithofacies, one basal, mainly pelitic and the other arenitic, in the upper part.

The Pontian has a transgressive character in the southern part, covering directly the Sarmatian or even older formations. The deposits, represented by clays and sandy marls with sandy intercalations, have a high lithofacies uniformity. The Pontian thickness is from a few meters to more than 600 m.

The Dacian covers transgressively the Pontian formation. It is represented by marls, calcareous marls, clays, sands, gravels and microconglomerates. The thicknesses of these deposits overpass sometimes 600 m.

The Romanian deposits are noticed at depths between 100 m and 600 m. The pelits and some sandy sequences predominate in its lithofacies constitution, without a uniform distribution. Marl clays and thin layers of coal lay in the Middle Romanian, characterized by a lenticular development. To the end of the Romanian, the Pliocene lake retreated and its evolution to colmatage continued in the Quaternary.

The Quaternary deposits are largely developed in the Bucharest zone and its environs (Fig. 4). The description of the sequence of the formations of the last cycle of sedimentation and the geological cross-sections (Fig. 5) is based on the boreholes plotted on the same map (Fig. 4). The large amount of geological, hydrogeological and geotechnical data (the geotechnical boreholes alone are more than 10,000) makes it possible to know the lithological succession from the bottom upwards for the Lower and Upper Quaternary deposits (Mândrescu, Capră, 2003). Some of the boreholes drilled in the city area considered in this work are represented in Fig. 6. The deeper boreholes outlined the following succession:

a) ***The Frăteşti layers***, common to all the deep boreholes, consists of three layers of sand and gravel, named A (upper layer), B (middle layer) and C (lower layer), separated by two intercalated layers of clay (Fig. 7). The layers have a similar structure, with coarsely sands and gravel at the bottom, and medium-fine sands transforming gradually to clays at the upper part. Thus, the grain size decreases from the bottom to the top of each layer, however we cannot say that this is an invariant characteristic of the sedimentation process. Sometimes we find gravel without sand at the bottom, while in other cases alternations of sands and gravels are observed or only sand succession with different grain size gradation. Borehole data indicate that the gravels are not concordant, but show a lenticular structure, characteristic for the torrential regime in which they were deposited. Since the constitutive material of the gravels (quartzite, gneisse, granite, conglomerate, sandstone, jasper) belongs both to the Carpathian and the Balkan domains, some authors consider that these gravels have a mixed Carpatho-Balkan origin (Bandrabur, 1961), opinion supported by paleontological arguments, as well.

The entire complex is gently descending from S to N, in opposition to the relief which descends from N–NW towards S–SE. The complex of the Frăteşti layers becomes thicker along the same direction.

b) ***The marl complex (Uzunu)***, represented by a succession of marl and clay, sometimes sandy marl with intercalation of fine sands. These deposits outcrop in proximity of Uzunu locality on the Câlniştea valley (Fig. 2). The mass of these deposits shows gradual changes from typical clays to clays with sand, sandy clays and sandy loam. Sometimes the clays are transformed into compact marls, generally with numerous limestone concretions.

The rocks composing the marl complex correspond from a granulometric point of view to some lacustrine formations, in facies of shallow depth, in which the determinant material was represented by the pelitic fraction. The marl complex undergoes a slight descent from S to N, accompanied by an increase of the deposits thickness in the same direction.

c) ***The Mostiştea sands***. The upper part of the marl complex is continuously covered by a bank of sands of brown-black color, with rust-colored intercalations. The granulometry reveals from fine and coarse sands to sands with intercalations of small gravels and rests of silicified wood. In the Dâmboviţa–Colentina interstream the sands have a thickness of 10–15 m, but in other places we can find sandy successions with clay intercalations with a thickness of a few meters. The thickness of the Mostiştea sands is in general 10–15 m. Smaller thickness is present in the western part of the city (Cotroceni plain), in the Giuleşti zone and in the Băneasa plain.

d) ***The intermediate clay deposits*** are developed between the Mostiştea sands and the Colentina sands and gravels. These clays have variable thickness, between 5 and 20 m. The largest thickness occurs on the Dâmboviţa–Colentina interstream. In a few places in the eastern part, the clays are completely laminated, and this results in mixing the Mostiştea sands with the Colentina sands and gravels. The intermediate deposits contain clays, silty clays and silty sands with abundant limestone concretions.

e) ***The Colentina gravels and sands*** show a transition from gravels, located at the basement of this complex, to sands, placed at the upper part. The entire deposit has a sedimentation in lens, with dimensions increasing to the bottom layer, regardless of the material composition (fine sands or rough gravel). This observation demonstrates that the sedimentation conditions evolved from a torrential regime (when the running waters deposited the gravels in the basement) to a more quite stage that allowed the sedimentation of the fine sands in small lens.

The same layer has a thickness of 5–10 m in the Băneasa–Pantelimon plain, with a structure of lens; in some places the thickness is only 3–4 m. The thickness of gravels and sands is 10–15 m in the Dâmbovița–Colentina interstream, has the smallest values in the Cotroceni–Văcăreşti plain (1–5 m in the zone of Ghencea avenue), increases to 10 m eastward of the Antiaeriană street and to 15 m in Olteniței street area and eastward of the Măgurele street.

f) ***The loess-like deposits***, with a lithology characterized by a large variety of granulation of the component elements, from clays and silt to fine sands and sometimes even coarse sands. The deposits structure is rather uniform and partly independent of the granulometry, displaying as lenticular aggregates more or less claylike, with calcareous and manganese separations. The loess-like deposits in the Bucharest area differ from the rest of the deposits of this kind in Romania, and from the typical eolian loess.

These deposits have a visible stratification or pseudostratification, a small percentage of fine particles, with coarser intercalations or even gravel elements, and an uneven distribution of carbonates, deposited naturally in the initial stage. Consequently, we consider that these deposits are of proluvial origin, built up during the process of aquatic dragging and deposited by the running waters. The mass of these deposits includes 2–3 levels of darker color, with a higher percent for clays, so called “fossil soils” and “buried soils”. The high content of clays is caused by eluviation phenomena of the proluvial deposits, during the time intervals of stagnation of the accumulation process.

Two distinct horizons of loessoid deposits were identified on the territory of Bucharest: old loessoid deposits, lying between the Mostiştea sands and the Colentina gravels and recent loessoid deposits, lying above the layer of the Colentina gravels.

The lithological sequence of the Quaternary deposits beneath Bucharest city is well represented in the cross-section made by Liteanu in 1952 (Fig. 8).

3.2. STRUCTURE

The map of the Neogene/Cretaceous boundary (Fig. 9) and geological cross-sections (Fig. 5) outline some of the peculiarities of the geologic evolution in the area of the city and its neighborhood. Thus, starting with the Upper Cretaceous the Moesian Platform underwent a process of uprising and remained exondated until the beginning of the Badenian, when a new basin of sedimentation started to be created. This basin would be preserved, with a few variations of the shore, until the end of the Pliocene, and in the lacustrial form, until the Quaternary. The surface of post-Cretaceous erosion has a slight plunge from south to north, to the Bucharest city position, after then, the slope is increasing, forming a transition zone towards the foredeep. Thus, the Cretaceous surface is placed at about 250 m depth at Călugăreni, in the southern part (F 210), at a depth of 927 m at Bragadiru (F199), approximately 20 km to the north, and at about 2,180 m depth at Moara Vlăsiei (F 201). In the case of other boreholes located in the northern part of the studied area (Tărtăşeşti – F204, Poiana – F204, Periş – F203) the Cretaceous was identified at deep levels as well (2,150 m, 2,340 m and 2,800 m, respectively).

The Miocene and Pliocene formations are transgressive, the more recent terms successively covering, from north to south, the older formations. One may note that the Sarmatian goes far beyond the limit of the southern extension of the Badenian, delimiting approximately the border between the external side of the foredeep and the platform. Note also a gradual sinking of the sedimentary cover from south to north and equally the increase of its thickness along the same direction.

The boreholes and seismic prospecting have identified a series of faults that, at first sight, have a chaotic distribution. But, a more careful analysis shows the existence of two major directions: one oriented approximately east-west, parallel to the structures of the Carpathians orogen. Along this direction the platform sinks in steps towards the north; the second, oriented north-west–south-east, rather perpendicular to the first direction, includes several faults, among them the most important is the system Belciugatele, located in the eastern part of the studied area (Fig. 9). All the faults have regional extension and affect the entire sedimentary layer, up to the Pliocene, inclusively. The Urziceni–Jugureanu fault, with its possible extension towards Căscioarele–Stoeneşti, is one of the most important faults of the platform. According to Paraschiv (1979), most faults can be followed only within the pre-Neogene formations and at the boundary Neogene/Cretaceous. The faults cannot be identified any more or are difficult to be followed in the Neogene, due to the step reduction, or to the lack of lithological contrasts (contrasts in elastic velocities, respectively). The faults that cross the Neogene cover of the platform are, at least partly, older faults, reactivated several times. The most recent displacements along these faults took place after the Miocene end, in the Upper Meotian, respectively, when the oil and natural gases deposits from Bucharest neighborhood were created. In the upper levels of the Neogene cover the vertical jump of the compartments along the faults does not go beyond a few tens of meters. Certainly the jump of these compartments is more pronounced, at least in the Paleozoic and Mesozoic formations, as a result of the accumulation of the repeated stages of reactivation.

The complete succession of Pliocene and Quaternary deposits until the beginning of the Upper Pleistocene shows that negative vertical movements affected the whole region permanently. Evidence thereof is the large thickness of the Quaternary deposits as shown by geologic boreholes: around 300 m between Periş and Buftea and more than 500 m in the north-eastern part of the Romanian Plain.

The deep geological and hydrogeological boreholes drilled in the city area allowed to work out the maps at the Frăţeşti and Uzunu layers surface (Figs. 10 and 11).

4. SEISMIC MEASUREMENTS

It is well known that the local natural factors can strongly influence the effects of a major earthquake upon the built environment of an urban area. Therefore, it is essential to know in detail the geological and seismic features of the zones with high seismic hazard.

In the previous sections the regional and local geological conditions were analyzed, with special emphasis on the weakly consolidated Quaternary deposits beneath Bucharest city. Information referring to the seismic characteristics and especially to the distribution of the seismic wave velocity in the geological formations at the city area comes from three sources:

a) deep geological boreholes, which allowed to establish the stratigraphic sequence and lithofacial character of the formations representing the last cycle of sedimentation in the Moesian platform;

b) seismic measurements made in more than 200 sites with the portable seismograph FS_3 for microzoning purpose (Mândrescu, 1972, 1977);

c) seismic measurements in boreholes at INCERC, UTCB, Căţelu and Mayoralty area (Moldoveanu, 2000; Aldea *et al.*, 2000, 2002).

The difficulties related to the engenderment and recording of the seismic waves in boreholes, particularly at greater depth, can lead to significant uncertainties in the measured velocity. Therefore, the results obtained using borehole data are compared with data from the literature for deposits with similar characteristics: lithological composition, age and genesis conditions (Campbel, 1978; Goto *et al.*, 1978; Kawase, 1995; Kazama, 1995; Kudo, 1978; Murphy, 1978; Nicolaev, 1965; Shima and Ohta, 1968; Warrik, 1974; Yoshikawa *et al.*, 1978; Rogers *et al.*, 1983). The following average shear wave velocities have been finally adopted for the main lithological formations beneath Bucharest city: Backfill deposits and soil, 90 m/s; Loesslike deposits, 216 m/s; Colentina gravel and sand, 317 m/s; Intermediate clays, 327 m/s; Mostiştea sands, 360 m/s; Marl Uzunu complex, 421 m/s; Frăţeşti layers, >600 m/s.

Except the layers of intermediate clay that get thin in some places, or even completely disappear, the other layers are noticed in all the boreholes sufficiently deep drilled over the territory of the city.

Although the measurements are made in spots, the velocity of the seismic waves are characteristic for the entire layer since the material has a common source, way of formation and its subsequent evolution has taken place within similar lithofacial conditions. The fluctuations of the water level in the sedimentary basin determined by no means several changes of the lithological composition, passing from clays to sandy clays or sands, from marl to sandy marl or sand lenses, but these transformations have been made gradually and have not modified significantly the seismic behavior of the deposit as a whole. This is also outlined by the narrow interval of the velocity values obtained from seismic measurements in boreholes using down hole and up hole methods.

5. PREDOMINANT PERIOD OF OSCILLATION

Likewise other big cities hit by strong earthquakes (Caracas, Mexico City), the largest damage was noticed in Bucharest for the high-storey and flexible buildings (Seed *et al.*,1970; Mândrescu, 1978; Girault, 1986). Thus, the earthquake of March 4, 1977 caused the collapse of 32 (6- to 12-storey buildings) and large damage of tens of tall buildings (Mândrescu, 1990, 1992). The principal cause was considered to be the proximity of the building fundamental period (T) and the characteristic period of the geological deposit response beneath the city (T_s). The period of oscillation characteristic for different sites in the Bucharest area was evaluated immediately after the earthquakes, resulting values between 0.9 and 1.6 s. It was assumed, at the same time, that the entire package of Quaternary unconsolidated deposits is excited during the Vrancea large subcrustal earthquakes (Mândrescu, 1978; Mândrescu, Radulian, 1999).

Recent studies carried out within the National Institute for Earth Physics in Bucharest on the geological conditions in the Bucharest area allowed us to compute the period of oscillation characteristic for different sites, using the same relation used by Mândrescu in 1978:

$$T_s = 4H/v_s \tag{1}$$

where H is the thickness of the deposits located above the bedrock, and v_s is the average shear wave velocity for these deposits.

We consider as bedrock the compact horizon of the Frăteşti gravels, for which we adopted a shear wave velocity greater than 600 m/s. There is a lot of debate relatively to the bedrock definition. In general, a rock sufficiently stiff and in which local shaking variation during strong earthquakes does not occur, could be considered as a bedrock. Seed (1975) considers that any rock with shear wave velocity (determined *in situ*) of about 760 m/s or greater can be adopted as a bedrock. Since this value of the shear wave velocity is reached at approximately 152 m of depth, Seed considered that it is not necessary to go to deeper depth in order to determine the period of oscillation in a given site. The Task Group D of the project RER-79/014 adopted a minimum velocity of 600 m/s for the geological formations considered as a bedrock (1982).

Since the deposit lying above the bedrock (Frăteşti gravels horizon) is represented by a sequence of layers of different thickness (H_i) and shear wave velocity (v_i), to compute the average velocity we use the relation:

$$V_s = \frac{\sum_{i=1}^{n} V_i H}{\sum_{i=1}^{n} H_i} \tag{2}$$

The computation is made for the site of each borehole that attained the surface of the Frăteşti layers. The map of the predominant period (Fig. 12) is drawn by interpolating the obtained values. The shape of the isolines and the two sections plotted in Fig. 13, outline the increase of the predominant period from south to north, in correlation with the constant increase of the thickness of the marl complex in the same direction (Fig. 13-A). The predominant period increase on E–W direction is on the contrary insignificant, as the thickness of the marl complex is almost constant on this direction (Fig. 13-B).

6. CONCLUSIONS AND DISCUSSIONS

One of the main results of this paper is a better knowledge of the geological conditions of the subsoil deposits beneath Bucharest. A few new maps have been elaborated on the basis of the geological borehole data using GIS format: the map of the Neogene/Cretaceous limit, the map of the Frăteşti layers and the map of the Uzunu complex surfaces. The analysis of these maps and of the associated lithological sections outlines a constant sink of the layers from south to north and in parallel the increase of the Quaternary deposits. The slowing down of the subsidence process in the Upper Pleistocene and then its complete cessation is pointed out by the surface almost horizontal of the Uzunu complex, which shows only a few local and low-amplitude depressions. The layers situated above this complex, starting with the Mostiştea sands, are also almost horizontal.

The average shear wave velocity has values within a relatively restrained interval, because of the petrographical composition of the layers of the subsoil. Therefore, the value of the predominant period is determined mainly by the thickness of the Quaternary cohesionless deposits, as already known for a long time (Omote *et al.*, 1956; Seed, Idriss, 1969; Seed, Schnabel, 1972; Goto *et al.*, 1978; Kudo, 1978).

The marl complex, with the thickness between 47 and 130 m in the city area, has the greatest influence in the computation of the predominant period. The predominant periods of oscillation computed in this paper have values between 0.9 and 1.9 s and correlate well with the values observed at the seismic Bucharest station (Radu, 1965), as well as with the value obtained on the basis of the spectral analysis of the accelerogram recorded at the INCERC station during the event of March 4, 1977.

The distribution of the predominant periods over the Bucharest area, anticipated in a previous paper (Mândrescu, 1978), puts up-to-date the recommendation made by Ghica in 1953 that drew attention on the necessity to avoid tall and elastic buildings in Bucharest. Designers and civil engineers ignored the recommendation until the March 1977 earthquake and consequently the vulnerability of all the tall buildings raised between 1963 and 1977 was amplified. Thus, the factor of dynamic amplification (β) introduced in the computation of the resistance structure of the buildings referred to values of the corner period (T_c) of 0.3–0.4 s, values typical for the response spectrum of the Imperial Valley earthquake (California) of May 18, 1940. But this event (M = 7.0) occurred at a depth of 16 km and was recorded at El Centro at 8 km epicenter distance, while the Vrancea event (M = 7.2) occurred at a depth of 94 km and was recorded at 165 km epicenter distance. Also, the bedrock at El Centro is at a depth of 32 m, while in Bucharest it is at 120 m. After the earthquake of March 1977 a new corner period was chosen (T_c = 1.5 s) in agreement with the maximum of the acceleration response spectrum recorded at the INCERC station. The difference between the principal parameters of the two earthquakes is outlined in Fig. 1.

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