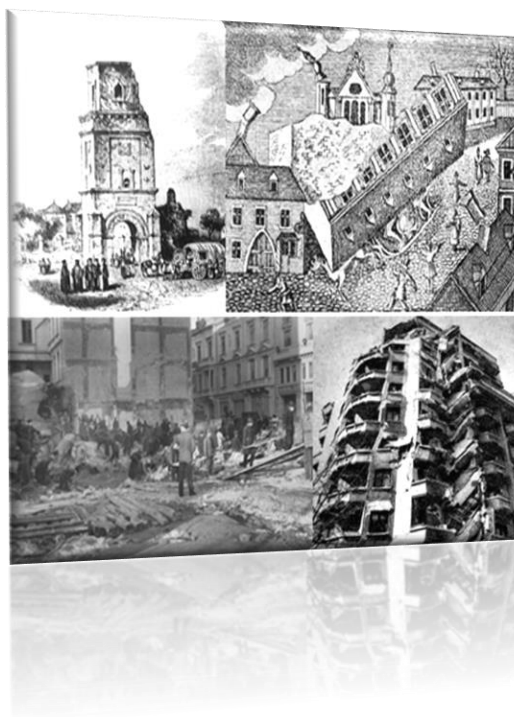


Research report No. 2

THE HISTORICAL MAJOR EARTHQUAKES FROM ROMANIA AND THEIR CONSEQUENCES ON BUILT ENVIRONMENT



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Chapter 1.

THE SEISMICITY OF ROMANIAN TERRITORY

1.1 Generalities

Earthquakes are natural geological phenomena, with destructive character, of varied nature and origin, of which the tectonic earthquakes are of a special importance [1]. These phenomena are characterized by complexity, both in terms of generating mechanism and unpredictability, also by its devastating consequences on humans and built environment (superficial topological changes, due to ruptures of the earth's crust and landslides, etc.). The manifestation of earthquakes, as well as the consequences caused, still it have a dramatic effect on human psychology, regardless of age and degree of culture, aspect accentuated and the unpredictability of such phenomena [2].

A representative event in the direction of seismic hazard assessment at the international level, was represented by the *VIII World Conference on Seismic Engineering* (1984 - "*The role of Science and Engineering in Natural Hazards*"), which defined seismic phenomena, thus: "*Earthquakes are a very special type of natural hazard, in the sense that they occur very rarely, with a low probability, but whose consequences, when they occur, expressed in human destruction and suffering, are very important*" [3].

Also, the researcher Vitelmo V. Bertero (Professor Emeritus of the Department of Civil and Environmental Engineering, University of California, Berkeley), defined earthquakes in his report entitled "*Codification, design and application*", presented in the II- of the International Conference on the Behavior of Metal Structures Located in Seismic Areas - STESA '97 (Kyoto, August 3-8, 1977) as follows: "*Earthquakes are natural disasters characterized by the fact that most human and economic losses are not caused by seismic movements themselves, but mainly the collapse of man-made constructions and facilities (buildings, dams, bridges, transport systems, etc.) in order to ensure the comfort of its existence... [...]... earthquakes are forms of hazard to which we it is in our power to answer them effectively. We can learn where we should not build and how to build to avoid the collapse of our buildings*"[4].

1.2 The origin and the cause of the earthquakes

The earth is in a permanent motion and has a rather complicated internal structure, which can be schematically reduced to the model in Figure 1. Based on the theory of plate tectonics, taking the older idea of the German meteorologist Alfred Wegener, according to that the earth's crust is made up of a number of rigid plates and subplates (blocks), which rest on the thick mantle melting under pressure and colossal temperatures, which determine the continuous movement of the plates, some in relation to the others. In this context, the continents movement continuously and slowly, producing changes in the earth's crust due to energy accumulations in rocks and volcanic eruptions, generating ruptures and large collapses inside the lithosphere.

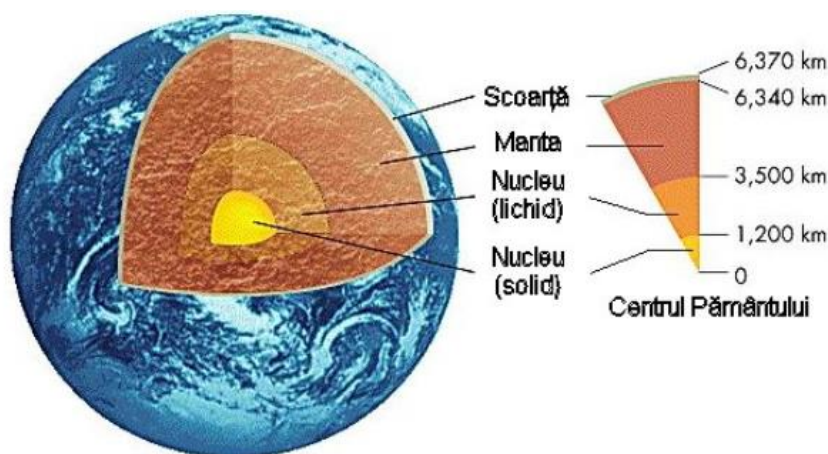


Figure 1- Schematically earth structure

Earthquakes which occur worldwide, are classified according to the two main sources:
i) *volcanic eruptions - volcanic earthquakes*; ii) *permanent structural changes of the earth's crust - tectonic earthquakes*.

The most frequent earthquakes are of tectonic origin, and the energy it releases extends over large areas of the crust [5]. Seismic shock occurs as a result of fracturing rocks that come in contact in a weaker plane in which extremely large elastic deformations have accumulated over time. The phenomenon of sudden release of this energy, instantly transformed into kinetic energy, generates the so-called elastic waves, which propagate radially, and through the process of refraction, they reach the surface.

The theoretical point where the initial rupture occurs, which in reality represents a fracturing area in the tectonic structure, is called the focus (hypocenter), and the point on the surface of the earth's crust, vertically of the focus, is called the epicenter, Figure 2 [5] .

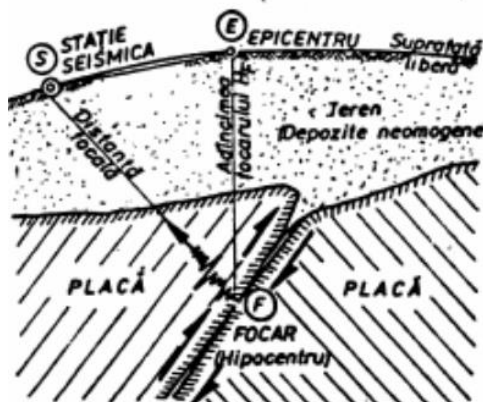


Figure 2 - Schematic pattern of earthquakes mechanism with tectonic origin [5]

Depending on the position of the outbreak, earthquakes are classified as follows: i) *crustal earthquakes* (normal) with approx. 70 km depth; ii) *subcrustal (intermediate) earthquakes* have the focus located in the interval $70 \div 300$ km, characterized by a significant moderate duration, with longer predominant periods, and the manifestation area is larger in relation to the crustal ones; such earthquakes are rarer, being found in Afghanistan, Colombia, Mexico and Romania [2]; iii) *deep earthquakes (depth)* have a focus located in the range of $300 \div 700$ km, such earthquakes being rarer and have a significantly longer duration [2].

The phenomena that occur in the depths of the earth's crust, at the level of tectonic plates, and which are at the origin of earthquakes are: i) faults - fractures of rocks in the lithosphere, caused by movements caused by landslides along a rupture plane, accompanied by the sudden release of a colossal kinematic energy transformed into seismic waves (primary depth P and secondary S, and the surface Love - L and Rayleigh - R), which propagates through layers of tectonic rocks; these rupture plans are called faults, such earthquakes are extremely violent (destructive) [2]; ii) subduction - tectonic plate theory claims that by strong compression, which manifests itself at the contact between continental plates, there are large displacements either due to subsidence, rock crushing, or due to the phenomenon of subduction (relative sliding of one plate under the other) [2].

1.3 Seismotectonic characteristics of earthquakes in Romania

Romania is one of the countries in the world subject to a persistent, periodic and severe seismic regime, coming from sources of tectonic character of great diversity. The written history, from the last half of the millennium, attests a sustained seismic activity on the territory of our country.

In this sense, the old chronicles, which are the first source of information, in chronological sense and of indisputable value, on the seismic activity in the Romanian countries, reflect in many details of many earthquakes occurred in these regions, their disastrous effects and concern. population, throughout history, to the seismic risk, represented by Vrancea seismogenic source, Figure 3 [1].

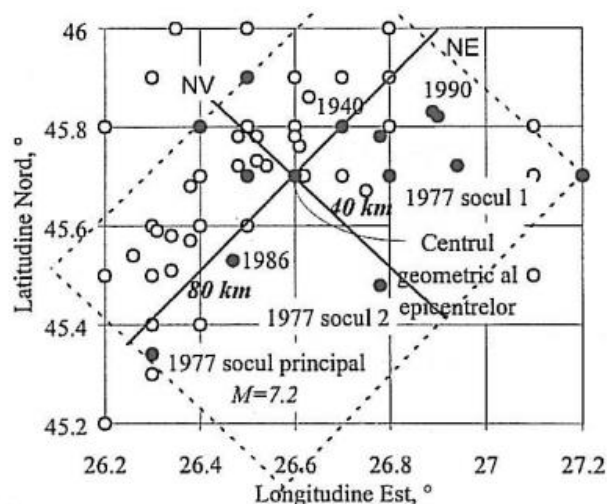


Figure 3 – Model pattern of Vrancea seismogenic source [3]

According to B. Gutenberg and Ch. F. Richter, the earthquakes that occur in Vrancea are similar, in terms of outbreak mechanisms, to those that occur in the Hindu Kush Mountains (Afghanistan) and Bucaramanga (Colombia). The outbreaks of Vrancea earthquakes are generally located at depths of approx. $70 \div 170$ km, but the most frequent and violent are those whose outbreak is located at depths of approx. $130 \div 150$ km. [2].

From a tectonic point of view, the Romanian territory consists of a conglomeration of converging plates and subplates in the Vrancea area, at the Carpathian Mountains Curvature. The Alpine-Carpathian-Caucasian belt, with an extremely complex geological structure, located at the western end of the Eurasian plate, includes the subplates of the Western Mediterranean, the Pannonian and Transylvanian area, as well as the Aegean Sea, being delimited by the Carpathian-Balkan Mountains. The subplates located in the South of the Carpathian Mountains, connected with the Balkan ones, globally define the Moesica subplate, Figure 4 [2].

A specific aspect of the Vrancea source is represented by the fact that the energy released in the hearth propagates mainly on the NE - SW direction and very weakly on the NW - SE direction.

This propagation, in the mentioned direction, has had, throughout history, either symmetrically distributed effects in relation to the epicenter area, highlighting some local areas of high seismic sensitivity at relatively large distances from the epicenter (southwest to the Danube and even beyond, and to the northwest, to beyond the Prut), as was the case of the earthquake of November 10, 1940, or asymmetrically distributed effects, frequently affecting areas of Moldova (hence the name of Moldovan earthquakes) [1].

The strong seismic movements generated by the outbreaks in Vrancea, in addition to the high intensity (up to grade IX - MSK), have a peculiarity, compared to the strong seismic movements that currently occur in other countries and are due to surface earthquakes. This particularity is manifested by the presence of long predominant periods of land movement in certain areas, including Bucharest, which must be taken into account in establishing the seismicity of different areas [1].

The experience of the earthquakes of 1977 and 1986 confirmed the fact that this particularity of the predominantly long periods in Bucharest is given by the local ground conditions (the presence in the surface area of a package of thick layers of mostly clay soil of about $50 \div 60$ m, in the East, South and center areas of Bucharest), characterized by long periods of $1.4 \div 1.6$ s of ground vibration in case of earthquakes of moderate and high intensity. This aspect favors, in the case of strong Vrancea earthquakes, the appearance of quasi-resonance phenomena for tall and flexible buildings, buildings that were affected by the earthquake of March 4, 1977 [3].

1.4. Seismicitatea teritoriului Romaniei inainte si dupa 4 martie 1977

Naturally, from the point of view of seismic design, it was considered necessary a simplified and practical representation of the seismicity of the Romanian territory, which would allow the adoption in design calculations of seismic loads as realistic as possible, as seismicity varies from geographical area to the geographical area and, consequently, the seismic loading differ as such.

Internationally, specialized concerns in the field of seismic engineering and the approach to seismic hazard assessment and consideration of a seismic design practice of constructions, have appeared in developed countries constantly and periodically subjected to violent earthquakes, such as Japan, USA, Italy, etc. [1].

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Thus, the main problems of the concerns concerned aspects related to the seismic conditions in which the constructions are located, concretized as a rule, in the seismic zoning maps and establishing the ways of establishing the effective seismic loads on the constructions in a realistic and practical way, but also of the rules. specific calculation and constructive composition. All this has become the subject of the content of the first technical norms that appeared in some developed or developing countries, such as Japan, USA, U.R.S.S., Italy, etc. [1].

Obtaining, for the first time in the country, the first seismological data recorded instrumentally, during the earthquake of March 4, 1977 (the most significant recording was provided by the SMAC-B type accelerograph of Japanese construction, in the INCERC station - Bucharest), made possible the first real seismic zoning, specifies the territory of our country. Also, the processing of the data recorded then, highlighted the particular and complex unique character of the Vrancea focus and the generation mechanism, this being defined as "multiple seismic event with multisock character" [2].

The seismic motion of the ground, which during the earthquake differs from one point to another of the earth's surface, leads to differences both in intensity of motion and its spectral distribution, caused by differences in the nature of the wave propagation path and local geological conditions.

In order to achieve a more realistic picture of the geographical distribution of the characteristics of the seismic movement of Romania during the 1977 earthquake, the few recorded data and means of estimation were used by combining the observed effects on buildings and people.

For this purpose, the Research Center for Earth Physics and Seismology (C.F.P.S) distributed, at that time, through the county authorities, approx. 10,000 questionnaires (of which 2000 in Bucharest), especially in the area outside the Carpathian chain. In parallel, a specialist commission was set up, which prepared a report of the identified damages at approx. 18,000 buildings, in order to substantiate a new micro-zone of Bucharest.

The observations made on the behavior of the constructions highlighted the variability of the seismic intensity from one geographical point to another and also allowed the finding of significant differences between the effects produced by the earthquake of March 4, 1977 on some localities near Bucharest and differences inside these localities. . Thus, the map of macroseismic intensities was obtained, drawn up on the basis of the intensity scale MSK - 64 (STAS 3684 - 71), connected with the isosist map drawn up by the geophysical institute from Sofia - Bulgaria [1].

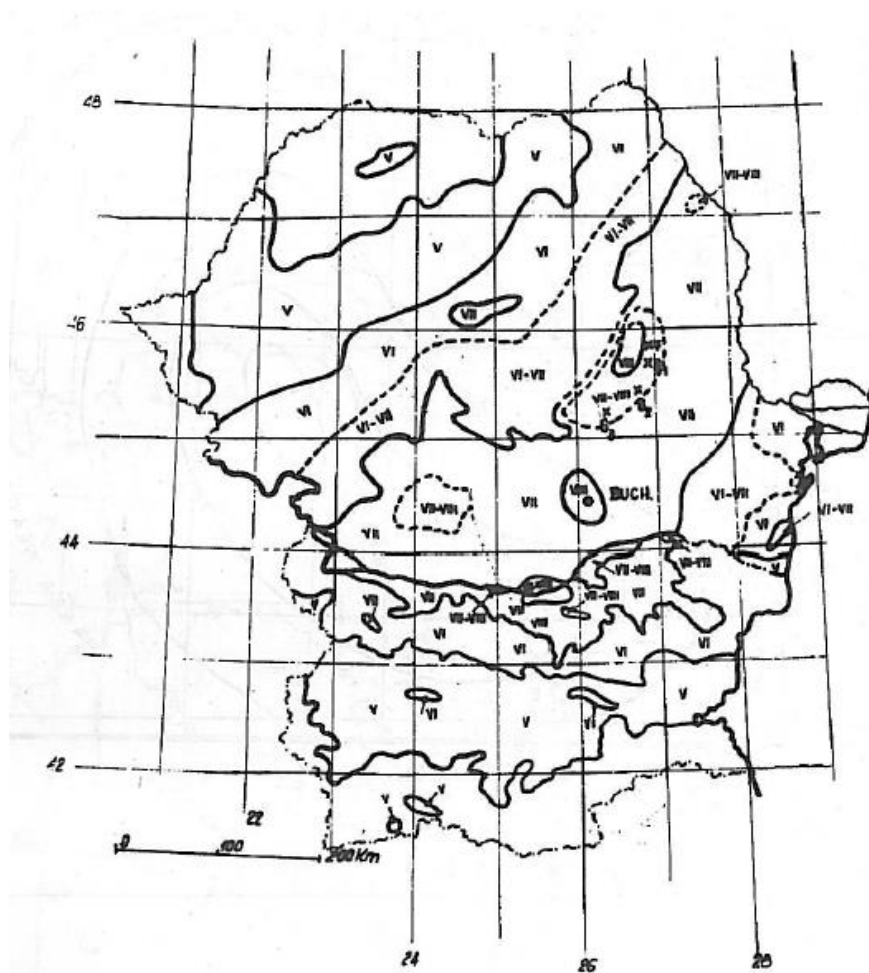


Figure 4 - Isoseismic map of the 1977 earthquake, Romania - Bulgaria [1]

On this map, of seismic intensities, there were at that time, a series of reservations from specialists in seismic engineering, in the sense that it showed an obvious tendency to underestimate the effects of the 1977 earthquake. presented in STAS 3687 - 71, for the evaluation of the seismic intensity according to the MSK - 64 scale, referred to the damages suffered by the rigid constructions, leading to intensities VI... VIII for Bucharest, and for the flexible ones, the intensities increased to VIII - IX and the fact that the level of anti-seismic insurance achieved for many constructions that entered the investigation was not taken into account, as a result of the application of the design norms in force in the period prior to the earthquake. This reservation was also supported by the Soviet seismologist S.V. Medvedev through the map with the isoseists of the 1977 earthquake proposed by him, Figure 4 [1], above.

Chapter 2.

THE EARTHQUAKES FROM 1802, 1829, 1838 AND 1940

2.1. The earthquake from 1802, 1829 and 1838

A synthesis of great value, regarding the Vrancea earthquakes and their historical records, can be found at the Romanian seismologist Gheorghe Mărmureanu [6]. Therefore, we find that the information on the historical earthquakes in Vrancea, which shook the territory inhabited by Romanians, was written in various documents of each era in chronicles, chronicles, daily, notes in books of worship (religious writings), generally written in the most important monasteries, for which writing is an important occupation, etc.

The earthquake of October 14/26, 1802 - was considered the largest in our country, in which there were a lot of casualties; the earthquake is included in the ROMPLUS catalog, in which it is associated with a moment magnitude $M_w = 7.9$ and a maximum intensity IX, and the depth of the outbreak at 150 km; in Radu's catalog, this earthquake has a magnitude $MGR = 7.5$, and in Shebalin (1974) $MGR = 7.5$ and intensity IX; this earthquake is considered "the great", it is felt from Ithaka Island to St. Petersburg and Moscow (Figure 2.8); the affected macroseismic area was 2 million km^2 ; according to Radu's catalog, effects are recorded such as "*the earth shook very much, as the holy monasteries were ruined*".

The memorial of the Valeni Monastery, Figure 5, in which they would be recorded: "In 1802, October 14 at 7 and a half hours there was a big and terrible earthquake that collapsed many holy monasteries, collapsing the holy Cotroceni Monastery" The Holy Monastery of Valenii de Munte also fell... And then, urging themselves to divine zeal, they first built the holy Cotroceni Monastery, i.e. the church, the bell tower and the big houses. They also built the Valenii de Munte Monastery on the holy Monastery... ”[7];



Figure 5 The memorial of the Valeni Monastery [7]

Among the churches and monasteries that suffered from the earthquake, it is worth to mentioning: Colțea (Figure 6), Stavropoleos, Săririndar, Sf. Apostoli, Sf. Gheorghe Nou, Mihai Vodă, Sf. Atanasie-Bucur, Cotroceni monastery and Văcărești monastery [8]. The Șerban Vodă Inn [15] was also demolished, i.e. the in where the National Bank is today. All culminated with effects on the environment „... the opening of the earth, water coming out of the earth and in some places ... tar...”[9].



Figure 6 - The collapse of part of the Colțea tower

The earthquakes of 1829 and 1838. Nearly three and four decades after the first significant earthquake of the nineteenth century (the one in 1802), two more major earthquakes would occur, those of 1829 and 1838, with an epicentral intensity of over 8. These caused casualties, panic, significant damage (cracks, cracks in the walls, etc.) and even collapse of the buildings of those times [6].

Thus, for example, at the great earthquake of January 24, 1838, of the magnitude of the one of 1802, produced in the Vrancea and Râmnicu Sărat areas, there were collapses of houses and many of them were severely damaged, including some buildings in stone masonry, which remained uninhabitable. Also, the peasants' houses, built of wood, suffered damages (light to moderate), and in Bucharest, this earthquake caused significant damage to many of the buildings of that time, few passing well (without significant damage).

Also at that time, the Palace of the Prince, the wall of St. George New, houses and shops collapsed; in conclusion, a total of 36 buildings collapsed then, apart from the damaged ones, and 8 dead and 14 injured were registered; there were also cracks in the ground on a length of 700-1700 m (eg in Lamotesti, on the northern bank of the river Milcov, a zig-zag crack was created on a length of about 800 m, these cracks closed later , after the earthquake) [6];

The effects of these seismic events, as well as that of 1802, were to be recorded in a French publication Voyage dans la Russie Meridionale et la Crimee par la Hongrie, la Valachie et la Moldavie par M.A.

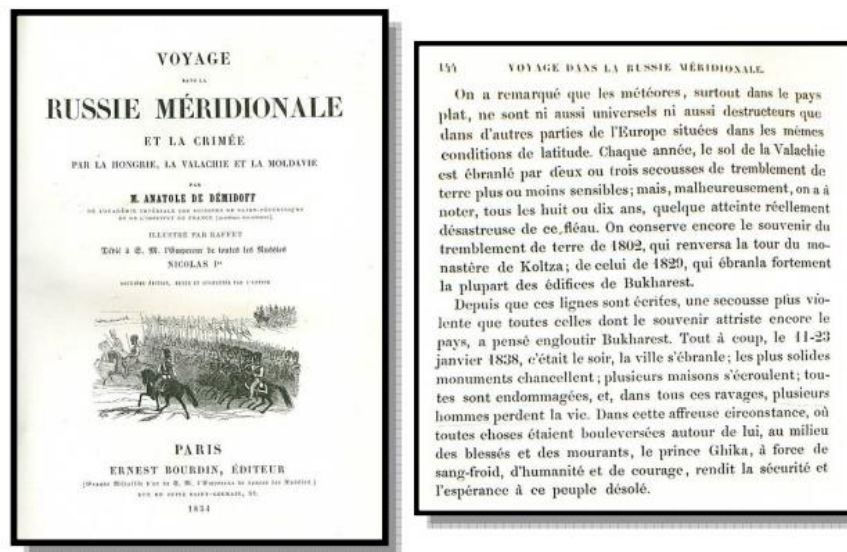


Figure 7 - Publicatia franceza Voyage dans la Russie Meridionale et la Crimee par la Hongrie, la Valachie et la Moldavie par M.A. De Demidoff, illustre par Raffet; E. Bourdine, editeur Paris, 1841 & 1854 [7]

De Demidoff, illustrated by Raffet; E. Bourdine, Paris publisher, 1841 & 1854, pp. 144, Figure 7, above: „ The memory of the earthquake of 1802, which overthrew the tower of the Koltza monastery, is preserved; of that of 1829, which severely shook most of the buildings in Bucharest. Since those lines were written, a more violent jolt than all those don't remember the country still saddens, thought to engulf Bucharest. Suddenly, on January 11-23, 1838, it was evening, the city was shaking; the strongest monuments falter; several houses collapse; all its damaged, and in all these ravages several men lose their lives ”[7].

2.2. The earthquake from 10 November 1940

On November 10, 1940, the first major earthquake occurred in modern Romania of the twentieth century, Romania which was already consumed in World War I and on the eve of World War II. This seismic event was characterized by a Gutenberg-Richter magnitude of 7.4, produced at a depth of approx. 140 km, epicenter of Vrancea.

The earthquake was characterized by serious consequences both in terms of casualties, over than 350, and in terms of significant property damage. In Bucharest, the most significant destruction was the complete collapse of the Carlton Block, which was the tallest reinforced concrete construction in Romania at that time (47 m high, 12 floors).



Figure 8 – Carlton Block: a) before the 1940 earthquake; b) before the 1940 earthquake

It was the first great earthquake in contemporary Romania, lasting 45 seconds. Its effects were devastating in central and southern Moldova, but also in Muntenia. The death toll was estimated at 1,000 dead and 4,000 injured, mostly in Moldova. Because to the context in which occurred, the exact number of casualties was not known, the information being censored during the war.

The earthquake was felt on more than 2 million square kilometers. The movement of the terrain was felt to the east in Odessa, Krakow, Poltava, Kiev and up to Moscow, where it caused some damage (estimated intensity V-VI). To the north the macroseismic area extended as far as Leningrad; to the west to the Tissa River, and to the SW and south, in Yugoslavia, throughout Bulgaria and further to Istanbul.

In Romania, two areas of maximum intensity have been identified a region that stretches between Panciu and Focsani, towards Tecuci and Corod, to Beresti and a second region that stretches from Campina to Bucharest, in the Romanian Plain. It is considered that in the two regions the intensity of the earthquake exceeded everywhere the eighth degree on the Mercalli-Sieberg scale, getting closer to the ninth degree which it seems to have exceeded at Campina, Focsani, Tecuci, Beresti and in a large number of villages from these regions, the maximum being found at Panciu, where the estimated intensity was X. In Vrancea, however, the intensity was lower, between grade VI and VII-VIII [6].

The year 1940 was characterized by a very high seismic activity in Vrancea, not only because of the earthquake of November 10 and its aftershocks, but, in reality, throughout that year there were many earthquakes of small magnitudes and intensities. Thus, since the first months of 1940, there were earthquakes in Vrancea which, according to catalogs, had magnitudes of $4.5 \div 5$ and took place at great depths of 130-160 km. In the middle of the year, more precisely on June 24, 1940, a magnitude 5.5 earthquake occurred in Vrancea at a depth of 115 km, easily felt in Muntenia and Moldova. A period of relative calm followed until the beginning of October, more precisely on October 3, 1940, when an earthquake of $4.7 \div 5.0$ occurred at a depth of 150 km [6].

On the evening of October 21, 1940, there were several earthquakes in Vrancea, the most important of which took place at midnight at a depth of 100 km ($M = 4.5$). In the morning of October 22, 1940, at 8 hours 37 minutes, in the Vrancea area there was a stronger earthquake, of magnitude $M_w = 6.5$ and maximum intensity VII to VII $\frac{1}{2}$ on the Mercalli scale, at a depth of $122 \div 125$ km; this earthquake was quite strongly felt especially in Muntenia and Moldova (with intensities that on a fairly wide area were VII degrees on the Mercalli scale). Only minor damage, cracks in the walls, broken windows, but no casualties were reported.

At the beginning of November, however, there were several earthquakes of over 4 at approx. 140-150 km deep. On November 8, 1940, at 2:00 pm, less than 2 days before the devastating earthquake, another 5.5 degree earthquake occurred in Vrancea at a depth of 145 km, an earthquake that was also felt in Bucharest. A day later, on the afternoon of November 9, 1940, there were several weak, local earthquakes in the area of Panciu, movements that went almost unnoticed by the population (II-III degrees on the Mercalli scale).

Finally, on the morning of November 10, 1940, at 3 and 39 minutes local time, the great earthquake broke out at a depth of about 140 km, with a magnitude of $M_w = 7.4 \div 7.6$ and maximum intensity $X1 / 2$. The worst consequences were reported in the south and center of Moldova, but also in the north-east of Muntenia. The city of Panciu was 90% destroyed, although most of the buildings were made of wood. Also, the cities of Focsani, Galați, Mărăsești, Tecuci and Iasi suffered great damage. Therefore, these earthquakes prior to the strong shock of November 10, 1940, anticipated its outbreak.

Academician Aurel A. Beles published in issues 10 and 11 of 1941 in the "*Bulletin of the Polytechnic Society*", as well as in a separate brochure, entitled "*Earthquake and construction*", but also in the French work "*Le tremblement de terre du 10 Novembre 1940 et les batiment* ", through these works, would discuss fundamental issues related to the specific seismicity of our country, antiseismic design and formulate, for the first time, the diagnosis of seismic vulnerability of all tall reinforced concrete buildings built in Bucharest, between the two world wars.

There were situations in which buildings in Bucharest, with metal or reinforced concrete skeleton, designed according to the official German design codes, at the 1940 earthquake, behaved favorably, they did not suffer any damage. Instead, there were situations in which reinforced concrete buildings suffered serious damage and even collapses, including the famous Carlton Block, as mentioned above. In particular, it was found that the high reinforced concrete buildings, similar to the Carlton block, were significantly affected, including the blocks: Belvedere on Str. Brezoianu, Lengyel, Pherekide, Brosteni, Galasescu, with 9 - 12 floors.

The structures of the buildings showed damage to the columns, both at the extremities and on their opening. Significant damage was located at the level of the columns by expelling the concrete and buckling the longitudinal reinforcements, these being limited to the first and second floors of the tall buildings.

Damage was also noticed at the level of the beams (cracks, dislocated concrete, flamed reinforcements, etc.). The filling masonry also suffered dislocations and cracks, due to a low tensile strength and a poor connection between it and the reinforced concrete elements. The buildings, where the masonry was made at the same time as reinforced concrete, behaved very well. The collapse of the Carlton block was the most unfortunate event.

Chapter 3.

THE EARTHQUAKES FROM 4 MARCH 1977

3.1. Generalities

The second important and large seismic event, which shook the territory of our country in the twentieth century, was that of March 4, 1977, which broke out at 21 and 22 minutes, with a duration of 60 seconds, with the epicenter in Vrancea. It was characterized by a moment magnitude $M_w = 7.4$, a Gutenberg-Richter magnitude $MGR = 7.2$ and a depth of 94 km, having a special importance, both nationally, by its characteristics. seismological (magnitude, focus mechanism, affected area with high intensity) and socio-economic effects (casualties, material damage, effects on construction), as well as internationally, it is felt from Sicily to Moscow and Leningrad, and in the South to Greece (according to the macro-seismic intensity distribution map developed by NV Shebalin) [10].

The earthquake of March 4, 1977 is considered, due to its effects, as one of the most destructive seismic shocks, which hit Romania in modern times, the depth of the last S3 shock was 109 km, near Pătărlagele-Buzău [88]. The first seismic wave trains were registered at different stations in the country, such as: Vrâncioaia, Focșani, Cheia, Bacău, Câmpulung Muscel, Iași, Bucharest, Deva and Timișoara. Below are the records of ÎCC stations, as follows:

- **recording 1** (Figure 9): INCERC - Bucharest, Street Pantelimon, No. 266, performed with a SMAC-B accelerograph, in the basement of a ground floor building, light, this representing the most important record, can be considered, practically, as a record of the undisturbed movement of the ground and characterized by weak oscillations, predominantly vertical, with a duration of approx. 18 s, strong oscillations, predominantly horizontal, lasting approx. 15 ÷ 20 s, with destructive effects and oscillations being attenuated, with a duration of approx. 40 ÷ 50 s;

the maximum horizontal acceleration, in the most unfavorable direction, exceeded 2.5 m/s^2 , corresponding to the degree of seismic intensity IX - MSK-64 (STAS 3684-71); also, for horizontal accelerations, long periods of approx. 1 s on the E-V direction, and on the N-S direction, 1.5 s;

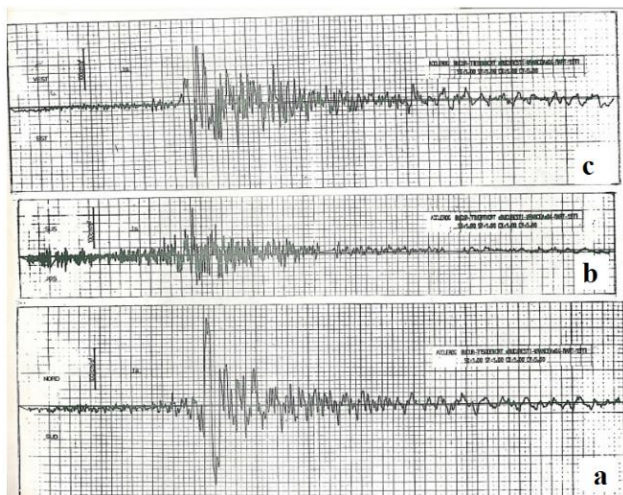


Figure 9 - Accelerogram of registration No. 1 - INCERC - Bucharest, Street Pantelimon 266;

- a) the accelerogram of the horizontal movement, North-South direction;
- b) the accelerogram of the vertical movement;
- c) the accelerogram of the horizontal movement, East-West direction [10]

- **recording 2** (Figure 10): Block E.5 - Balta Alba in Bucharest (a high and relatively rigid construction), provided by the MO-2 accelerograph mounted on the 9th floor and characterized by horizontal acceleration values of approx. $3 \div 3.5 \text{ m/s}^2$ and periods of approx. $0.8 \div 1 \text{ s}$, values much higher than the conventional ones for the structural calculation;

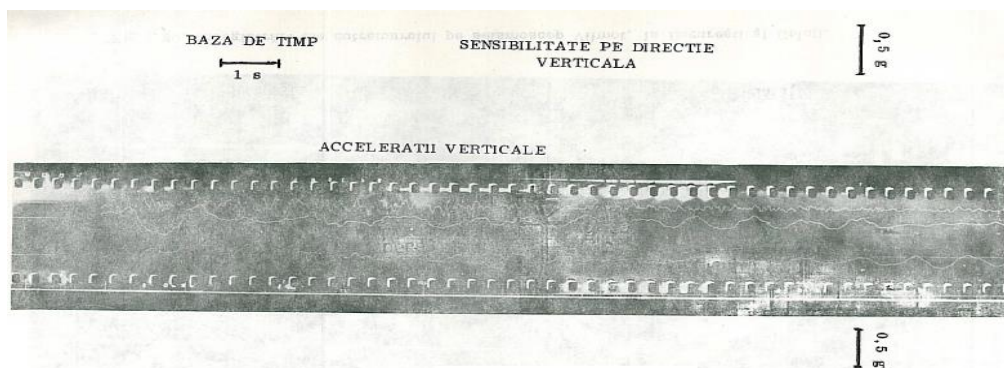


Figure 10 - Recording accelerogram No. 2, Bl. E5 - Balta Albă, Bucharest [10]

- **recording 3 and 4** (Figure 11, Figure 12): INCERC - Bucharest, Sos. Pantelimon and Galati, obtained at ground level, with the help of two Wilmot seismoscopes, these highlighting extreme oscillation speeds of approx. 0.42 m/s in Bucharest and approx. 0.27 m/s in Galati.

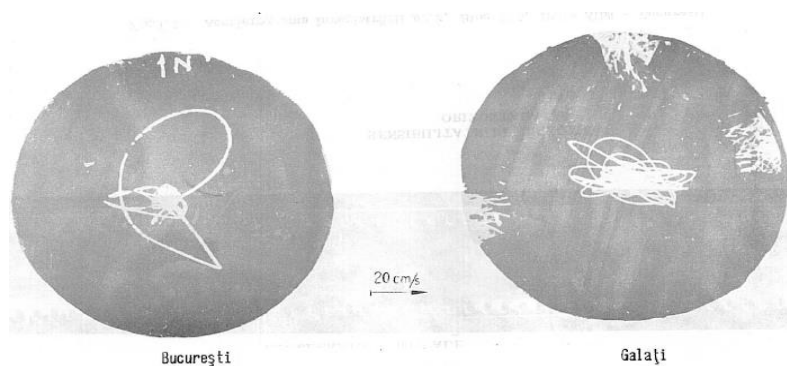


Figure 11 - Accelerograms of records No. 3 and Nr. 4, INCERC, Bucharest and Galați [10]

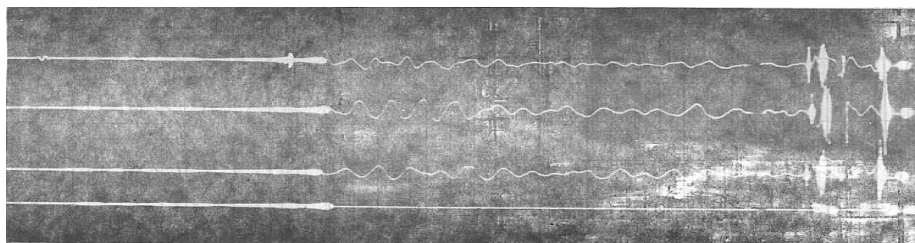


Figure 12 - Accelerogram of the registration from Vrâncioaia - Moldova station [10]

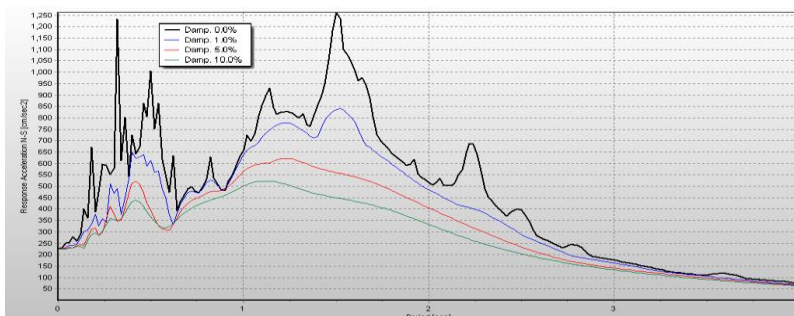


Figure 13 - Acceleration spectrum of registration No.1, component N-S

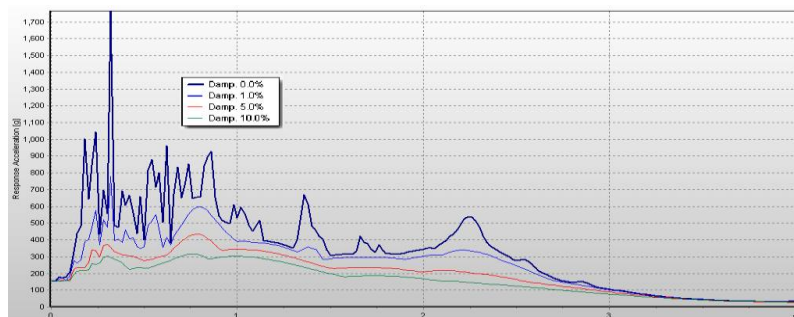


Figure 14 - Acceleration spectrum of registration No.1, component E-V

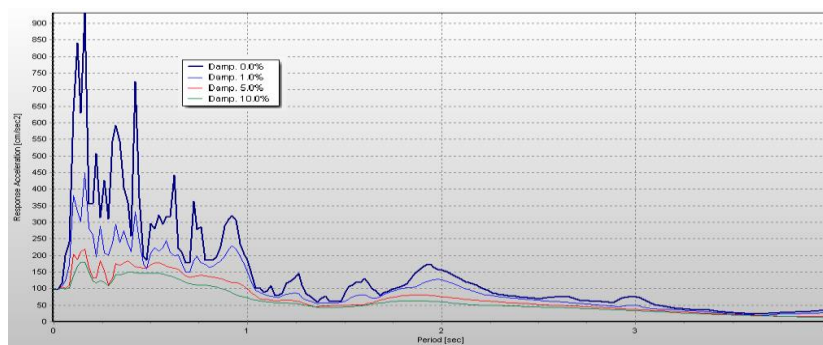


Figure 15 - Acceleration spectrum of registration No.1, vertical component

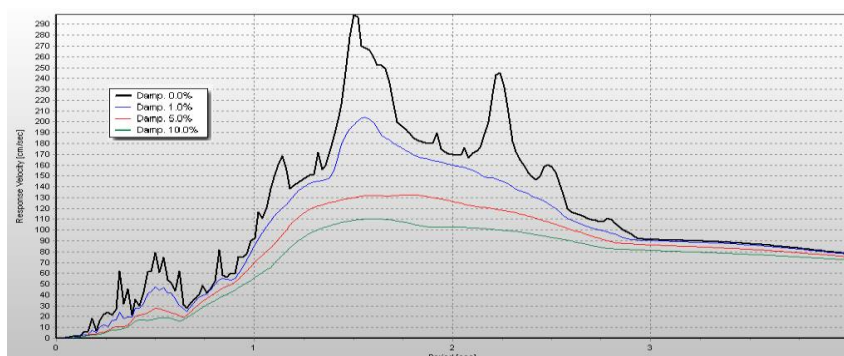


Figure 16 - Recording speed spectrum No.1, component N-S

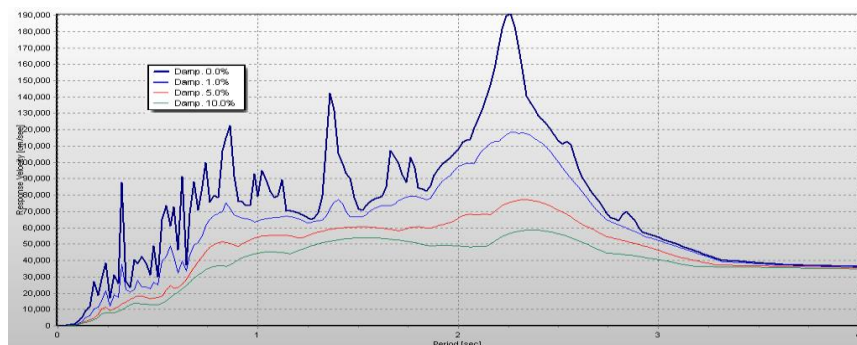


Figure 17 - Recording speed spectrum No.1, E-V component

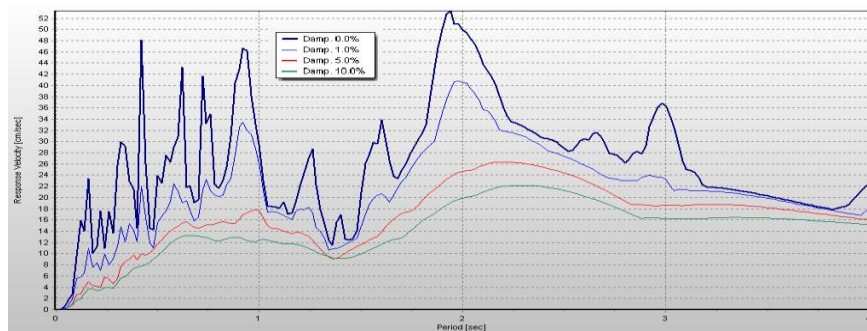


Figure 18- Recording speed spectrum No.1, vertical component

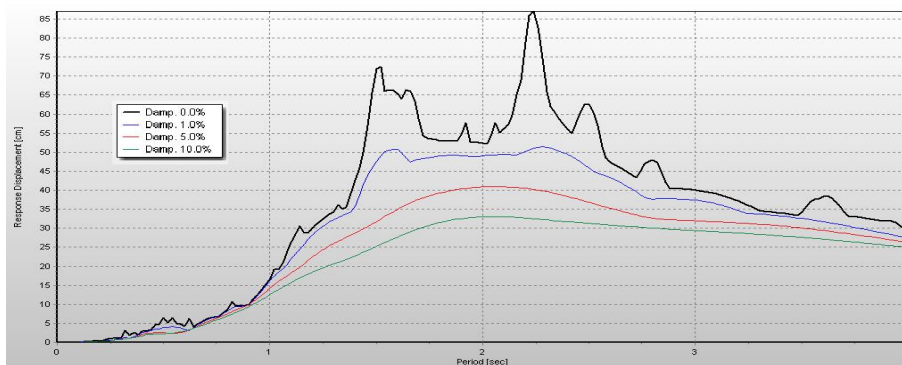


Figure 19 - Displacement spectrum of registration No.1, component N-S

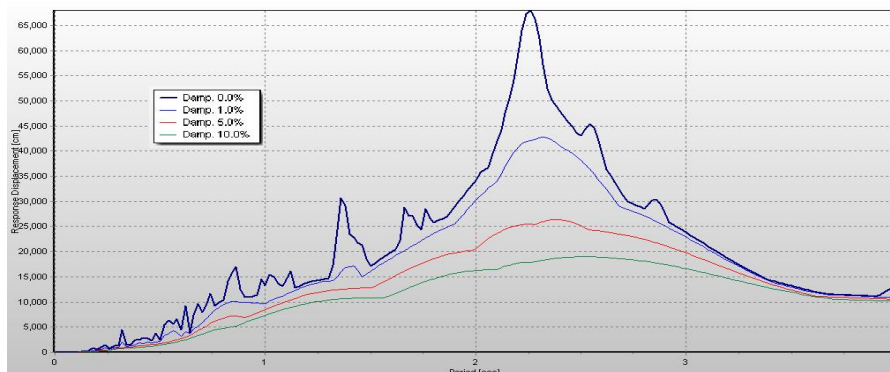


Figure 20 - Displacement spectrum of registration No.1, E-V component

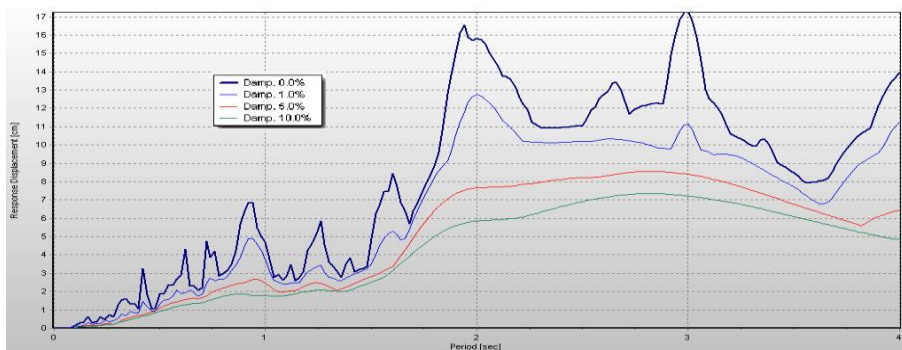


Figure 21 - Recording speed spectrum No.1, vertical component

At that time, instrumental seismoscope recordings were obtained from the city of Nis - Yugoslavia and recordings provided by seismographs mounted on the structures of buildings in the city of Chisinau - Republic of Moldova - U.R.S.S. (Figure 22 ÷ Figure 24). These highlighted long predominant periods of movement similar to those in Bucharest, but the peak accelerations had values of approx. 5 times lower, and speeds with values of approx. 8 times lower compared to the values recorded in Bucharest, and in Chisinau, the periods were approx. 1.5 ÷ 1.6 s and maximum ground displacements of the order of 7 cm.



Figure 22- Seismoscope earthquake recordings from Nis - Yugoslavia [10]

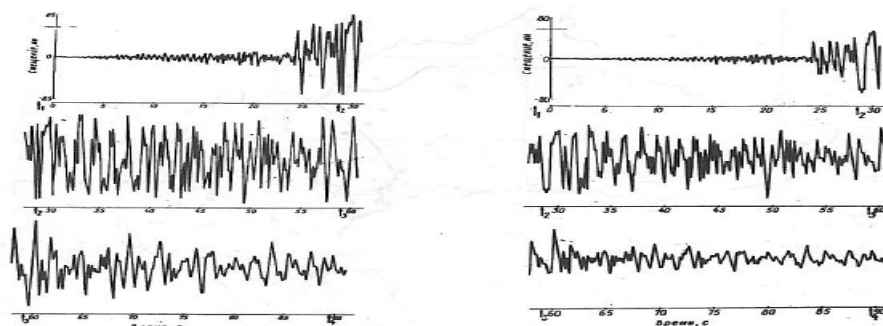


Figure 23 - Seismograms in the direction of transv. on the floors of a ground floor + 4 floors, large panel building, Chisinau [10]

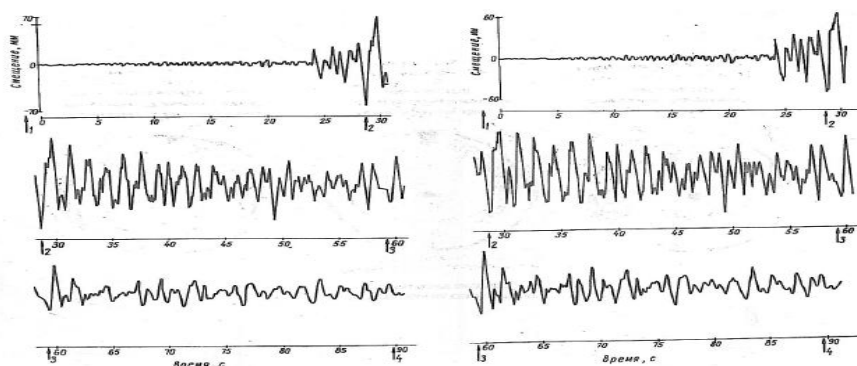


Figure 24 - Seismograms in the direction of transversal at the base of a ground floor + 4 floors, large panel building, Chisinau [10]

3.2 Geological phenomena associated with the 4 March 1977 earthquake

In general, major seismic phenomena lead to the onset of complex associated phenomena such as fires, floods, landslides, landslides, avalanches, etc., which often amplify the extent of damage to the built environment. The earthquake of March 4, 1977, declassified a series of complex phenomena, among which the most important were the typical geological phenomena for the Vrancea earthquakes, namely: i) fractures and cracks (Figure 25);

ii) cracks and fissures (Figure 26); iii) changes in the groundwater and surface water regime;
iv) gas emissions and muddy volcanoes; v) increase of natural radioactivity; vi) liquefaction of
aquifer sands; vi) landslides;

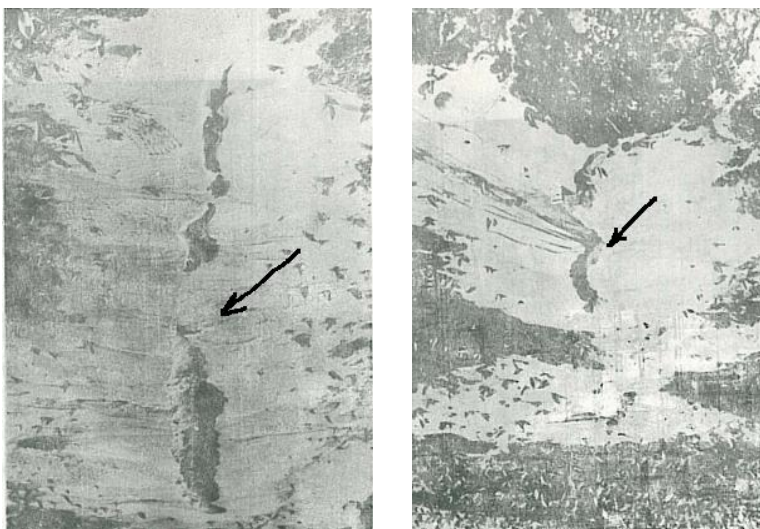


Figure 25 - Cracks with liquefied sand spring [10]

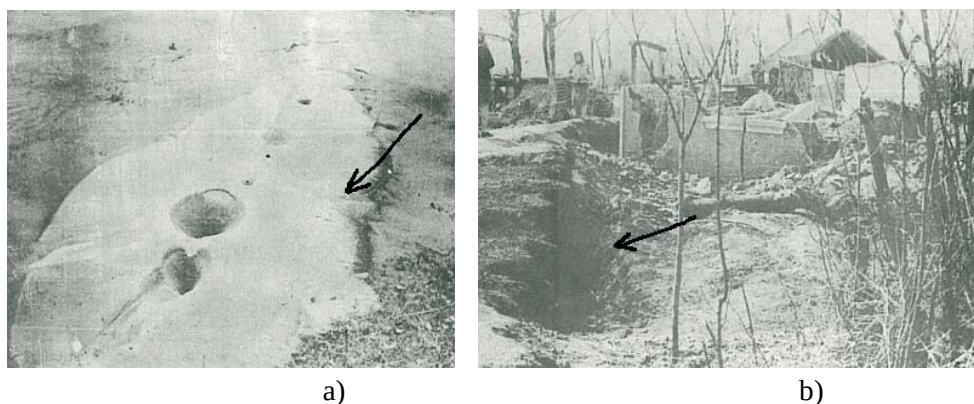


Figure 26 - a) liquefied sand; b) landslides [10]

3.3 The effects of the 4 March 1977 earthquake on peoples and construction

The powerful earthquake of March 4, 1977, produced at 21 and 22 minutes in the Vrancea seismic region, caused casualties and significant material losses, due to both the high intensity of seismic movements and large areas affected, which included many urban centers, with high construction density, especially in the south of the country.

Among the localities and industrial centers in the country, affected by the earthquake, the biggest losses of human lives and material damages occurred in Bucharest. Significant damage also took place in Zimnicea, Rosiorii de Vede, Craiova, Ploiesti and Iasi.

From the point of view of human losses, from the report of the Grand National Assembly of the Supreme Council of Economic and Social Development, resulted the following data on the loss of human and economic lives [10]: a) 1570 dead and over 11,300 wounded were identified, among which approx. 90% in Bucharest; b) 32,900 homes were collapsed or severely damaged, 35,000 families were left without shelter, and tens of thousands of other buildings suffered various damages; c) after complete evaluations, made later, resulted in material damages amounting to over 2 billion dollars at that time.

The earthquake of March 4, 1977 was the occasion to record, for the first time in our country, the dynamic characteristics by instrumental methods, thus obtaining the first essential accelerograms for processing and formulating antiseismic design principles, in accordance with the real seismic specifics of Romania. Also, this earthquake was a great opportunity to collect, for the first time, in a systematic way, a large volume of data and information on the behavior of strong seismic actions of many and various types of constructions, located in all areas affected by the earthquake.

3.4 Dynamic aspects of the behavior of constructions affected by the 1977 earthquake

Dynamic stresses, which act on a construction, can come either from deformations caused by differentiated displacements of foundations, or caused by seismic waves caused by deformations and stresses developed by forced oscillation of the structure under the effect of impulses received at the foundation.

In general, from the aspect of the influence of the nature of the foundation ground, on the degree of earthquake damage of the constructions, from the findings made at the 1977 earthquake, a good behavior of the foundation ground resulted. No cases of failures or degradations of the construction infrastructure were identified, which confirmed that the foundation solutions and sizing methods, adopted at that time, prior to the earthquake, were generally efficient.

The additional dynamic stresses, caused by the earthquake, at ground level - foundation, produced some additional settlements, as could be seen in Bucharest, Galati, etc., especially in areas located on meadow formations, of relatively low consistency or with lands sensitive to moisture, with a higher level of groundwater, but these settlements were small, of max. 20 - 25 mm, and generally uniform, without having serious direct consequences on the constructions.

3.5. General assessment of the effects of the 1977 earthquake in the most affected cities

Dolj County. Numerous urban buildings have been affected in Dolj County, especially in Craiova and rural areas, in the vicinity and in other localities in Lunca Jiului. In Craiova, where anti-seismic insurance measures had been taken, because the city was located in the area with grade 6, according to STAS 2923-63, and the real intensity of the earthquake was 1... 2 degrees higher, registering collapses of old buildings, in general, but also damaged buildings, many of them very badly damaged, located in the Valea Rosie neighborhood on the middle terrace of Jiu, in the South - East part of the city, with macroporic land. Judetul Teleorman

In Teleorman county, the cities of Zimnicea and Rosiorii de Vede were affected, and only to a small extent the city of Alexandria. In Zimnicea, a city located on the direction of maximum intensity Vrancea - Bucharest - Zimnicea, were severely affected, almost entirely, the old buildings, mostly made of heavy materials and low strength (brick masonry with lime mortar and masonry elements from clay and straw, called adobe), many of these buildings being on the verge of collapse, were later demolished. At that time, it is considered that an important cause that generated these severe damage in this area was of a geological nature.

Prahova County. In Prahova county, the most affected localities, with collapsed buildings and many severely damaged, were located in the central area of the county and south of the line that would connect Breaza with Mineciu and especially the city of Ploiesti (especially the central and northern area), the cities of Cimpina and Valenii de Munte, as well as the localities of Valea Calugareasca and Drajna.

Buzau County. In Buzau county, the effects of the earthquake were felt, especially, along the Buzau river valley, affecting especially the municipality of Buzau (where there were serious damages in the central area) and the localities of Patarlagele, Cislau, Calvinii, Chiojd and in small measure along the Râmnicu Sărat valley.

Iasi County. In Iasi, the constructions with the most important degradations were located in the alluvial meadow of Bahlui, in the neighborhoods of Socola - Nicolita, Mircea cel Batran, Alexandru cel Bun and Pacurari, where the foundation land was made of contractile clay, and the groundwater level was higher. However, there was a unique situation, namely the fact that in some areas with soil sensitive to moisture in the Tatarasti - Copou neighborhoods and in the central area, they behaved better.

3.6 Behavior of buildings during the 1977 earthquake

Among the multitude of factors that influenced the behavior of the constructions in the areas most affected by the earthquake of March 4, 1977, the factor had a special importance in its judicious evaluation: the period of construction. This factor implies, on the one hand the level of seismic assurance (the level of knowledge of this problem and the way of reflecting this knowledge within the technical regulations specific to the practice of design and execution of constructions), and on the other hand the age of the construction and the different external influences suffered by construction during operation until the time of the 1977 seismic event.

From this point of view, after the 1977 earthquake, the constructions in the country, especially those affected by the earthquake, were grouped in two important categories:

- **old constructions**, in this category were included the constructions made in two subperiods: before the earthquake of November 10, 1940 and those made in the interval 1941 - 1950; they were characterized by the lack of specific anti-seismic conformations, the absence of calculations at horizontal forces and the use of materials with reduced mechanical characteristics;
- **new constructions**, the constructions made also in two subperiods were framed: those made in the period 1951-1963, until the appearance of the first Romanian prescriptions for anti-seismic design (P13-63) and those made in the period 1963 - 1977; they were characterized by the existence at the base of the design and execution of anti-seismic insurance measures.

A fundamental aspect identified, surprisingly, was the fact that, in terms of the degree of anti-seismic insurance and the negative effect of external influences of old and new constructions, defined above, there were cases of satisfactory behavior of some constructions made before 1940. - old (based on a structural and rational conception, implicitly some accidental insurance to lateral forces, although they were calculated exclusively gravitational), but also cases of new constructions (designed based on antiseismic design prescriptions) that suffered unexpected damages grave.

The diversity of constructions behavior, in general, under the action of the earthquake of March 4, 1977, due to the dependence on a lot of factors, was highlighted especially in the case of residential, socio-cultural and administrative buildings, due to the fact that constituting the largest share of buildings located in different areas and centers severely affected by the earthquake, they suffered the most.

This category includes the entire range of varieties such as shapes, destination, construction, degree of earthquake resistance, quality of execution, age of construction, influences of periods of operation, etc.

3.6.1 Behavior of old residential buildings

From the point of view of the constructive composition, the old residential buildings, affected by the earthquake of March 4, 1977, had the specific structural typologies below [10]:

- **very old buildings**, they usually had a ground floor height regime (sometimes with a partial basement and / or partial floor), the load-bearing masonry structure and often the cobweb or adobe were made in solutions, they had wooden floors; such constructions were and still are, in rural areas and in the old (peripheral) neighborhoods of cities;
- **buildings with load-bearing masonry structure** with low height regime, either groundfloor+ 1... 2 floors for single-family dwellings, villa type, or groundfloor+3... 5 floors for collective dwellings; they often had irregular shapes both in plan and elevation, often developed in one direction, attached to the heel in a group of two buildings; the floors were made partly of reinforced concrete or brick and partly of wood, especially on the top level;
- **buildings with mixed structures**, with height regime groundfloor + 3... 6 floors, often attic, made partly of load-bearing masonry (generally perimeter) and partly with interior columns and reinforced concrete or metal beams, with floors in various solutions (vaults of brick on metal beams, reinforced concrete slabs and beams, wooden beams); these buildings did not have a clear construction scheme, in most cases, they had undergone various transformations during operation;
- **buildings with reinforced concrete skeleton**, with height regime groundfloor + 6... 12 floors, block type (made especially in Bucharest), having irregularly arranged pillars and beams, depending on the side of the apartments (without forming frames), often with discontinuities of floor to floor, as well as pillars with large eccentricities and often irregular shapes;

the presence of floors coming out of the console (bay windows) or additional floors, retracted in size, columns resting on beams and with great eccentricity in relation to the whole building; all these buildings used lower class concrete (generally B120).

None of the types of buildings with structural typologies, exposed above, were designed for seismic loads, and most of them did not comply with the minimum necessary design and execution rules.

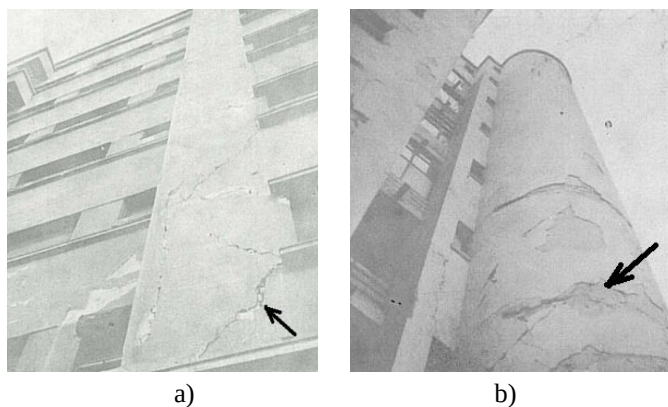


Figure 27 - a) Facade wall cracks; b) Masonry dislocated staircase [1]

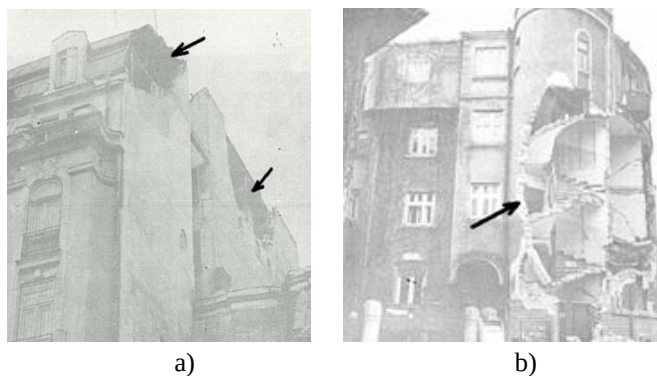


Figure 28 - a) Collapsed masonry heels; b) Facade masonry walls / collapsed staircase house [10]

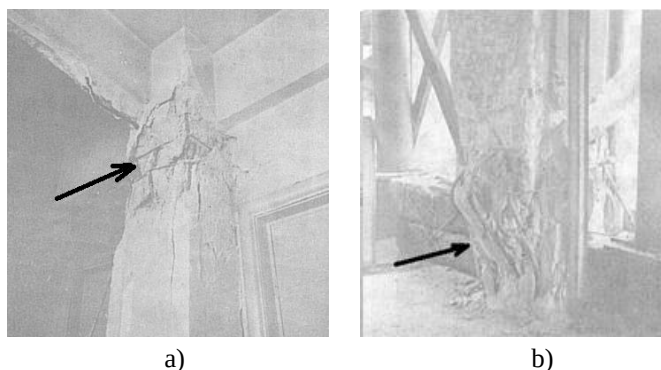


Figure 29 - a) Destruction of the column-beam node b) Destruction of the column at the base - ground floor [10]

Most of them have suffered damage since the earthquake of November 10, 1940, damage that was either superficially repaired or neglected, and other causes (deficiencies in design, execution, inadequate quality materials, etc.) have led to severe damage or even collapse in the March 4, 1977 earthquake.

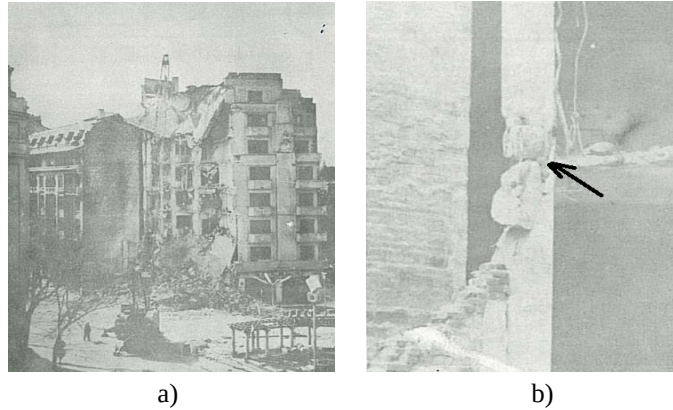


Figure 30 - a) "Lido" block of flats - Bucharest, building with reinforced concrete frame;
b) Completely broken pillar - "Lido" block [10]

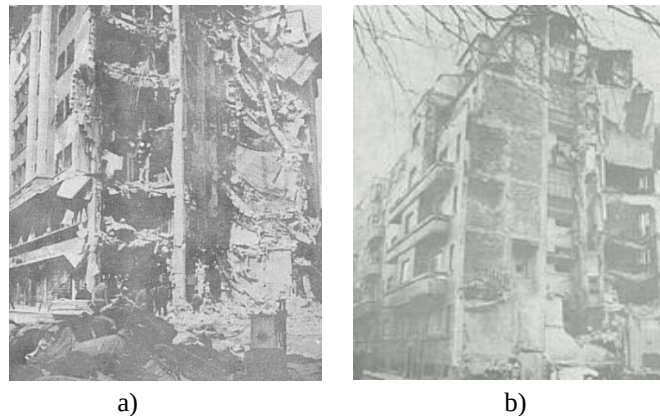


Figure 31 - a) "Danube" block of flats - Bucharest, building with reinforced concrete skeleton;
b) Block of flats - Bucharest, Str. Poenaru Bordea no. 18 reinforced concrete frame building [10]

From the point of view of earthquake behavior, the old residential buildings affected by the earthquake of March 4, 1977, suffered a series of damages specific to each structural typology:

- **old residential buildings** with load-bearing masonry structure and height regime P + max. 5E, damages were found such as:
 - open cracks and dislocations of the load-bearing masonry, with plans of approx. 45° or in the shape of "X", in some situations reducing the rigidity to the limit of their collapse;

- vertical cracks at the intersection of insufficiently woven load-bearing walls or above door gaps;
 - serious damage to the stairwell;
 - collapses of bridge trusses made of ½ brick masonry, thus causing damage to neighboring buildings;
 - collapse of chimneys in masonry;
 - situations in which they collapsed or on the verge of collapse, requiring subsequent demolition.
- Old buildings with mixed structures, made of masonry and reinforced concrete interior pillars (a type of confined masonry), behaved generally unfavorably, even in the case of those with reinforced concrete floors, due to the lack of interior walls of resistance, which would have ensured rigidity and capacity to take over the horizontal seismic forces.
- The tall old buildings with reinforced concrete skeleton, of block type, had a behavior determined mainly by two essential factors, as: on the one hand the general lack of conformity and seismic insurance (reduced sections of columns elements and / or beams, lack thereof, insufficient reinforcement, etc.), and on the other hand the destructive effects and visible or hidden damage, which occurred following the seismic event of November 10, 1940, which were not properly remedied. In these cases, it was found:
- because of the very high seismic forces, there were serious damages at the level of the filling masonry walls, these being incompatible with the large deformations of the structure;
 - severe damage to the pillars on the ground floor and from the first levels (generally in the corner and edge pillars were identified cracks or cracks open at 45° or approximately vertical); crushing of the concrete, in general, at one of their ends, with buckling of the longitudinal reinforcements and expulsion of the concrete on one or both sides from the direction of the seismic action, or even their complete rupture by the action of eccentric compression of the shear or by the combined action of their;

- the damage of the beams consisted in their cracking in the support areas (approximately vertical cracks, at 45° and horizontal along them towards the middle of the opening); crushing of the concrete towards the supports or even towards the middle of the opening, sometimes with the buckling of the longitudinal reinforcements;
- at the level of the floors, damages were identified in the form of fine to open cracks, transverse cracks in the floors or stairs of the stairs, especially at the changes of directives of the ramps;
- damage to non-structural elements (filling walls, partitions, etc.) in the form of accentuated cracks or open cracks, sometimes partial or total dislocations and collapses, especially at the lower levels of buildings;
- damage to the facade walls in the form of cracks or "X" -shaped cracks in the window sills, as well as damage to the bay windows;
- situations of collapses or the need for further demolitions due to the degree of damage at the limit of collapse.

3.6.2 Behavior of old socio-cultural and administrative buildings

In this category of buildings, there were, in general, specific degradations similar to those that appeared in the old residential buildings, with a similar structure. In terms of collapses, they occurred in small cases, the most important were registered in Bucharest, thus, four important buildings collapsed:

- The administrative building of the Ministry of Metallurgical Industry (“Carpathians” block) from Str. Academiei nr.7 (tall building with reinforced concrete frame structure), suffered a partial collapse of a corner of it between Str. Academy and Edgar Quinet, Figure 32;
- Administrative building - offices and shops (“Mica” block - Nestor Confectionery - tall building with reinforced concrete frame structure) from Calea Victoriei no. 63-69, suffered the total collapse of body A from Calea Victoriei, Figure 33;
- Victoria Hotel from Calea Victoriei no. 15 (low-rise buildings and load-bearing masonry structure), partially collapsed;
- Faculty of Chemistry from Splaiul Independentei no. 87 (buildings with low height and load-bearing masonry structure), suffered a partial collapse.

Regarding the damages suffered, they were similar to those that appeared in the old residential buildings, comprising to a large extent the categories of socio-cultural buildings made of load-bearing masonry or with a concrete structure.

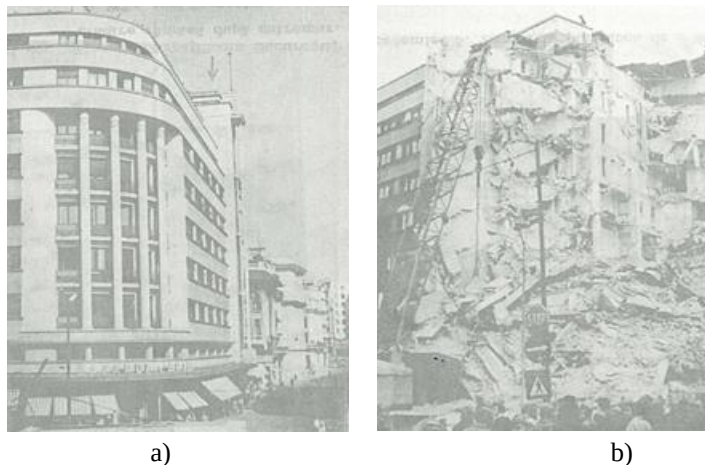


Figure 32 - Ministry of Metallurgical Industry ("Carpathian" Block) - Bucharest: a) before the earthquake; b) after the earthquake [1]



Figure 33 - The office block "Cofetaria Republica" (former Nestor) - Bucharest [10]

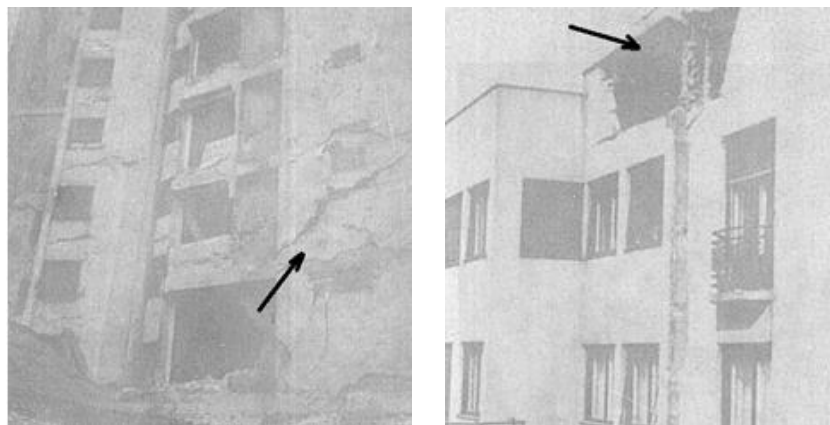


Figure 34 - Hotel "Ambassador" - Bucharest, damage to the facade [10]

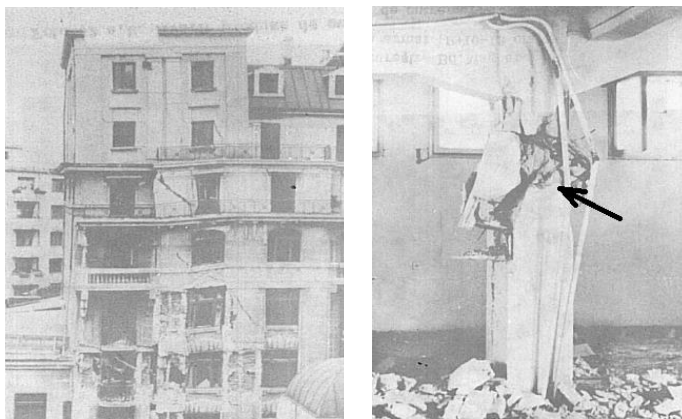


Figure 35 - Office building - ISPIF Institute - Bucharest, damage to the masonry on the facade, reinforced concrete bay windows and columns[10]

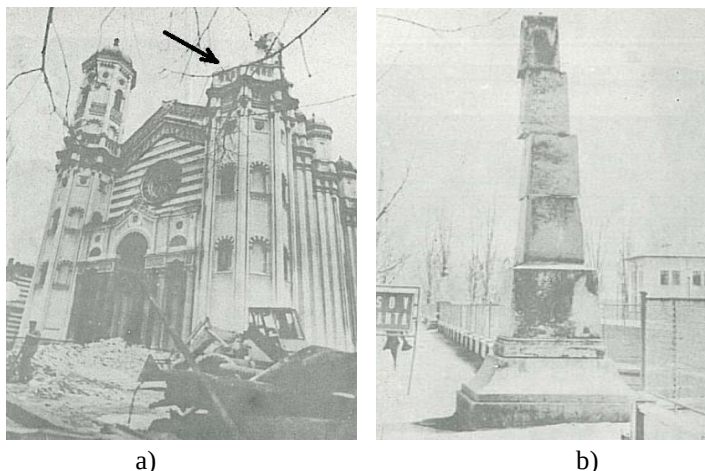


Figure 36 – a) St. Spiridon Church - Bucharest, right tower collapse; b) Obelisk from Bucharest located [10]

3.6.3 Behavior of new residential buildings

From the point of view of the constructive composition, the new residential buildings, affected by the earthquake of March 4, 1977, had the specific structural typologies below [10]:

- For buildings with low height (maximum 4 floors):
 - load-bearing masonry structure, generally reinforced with reinforced concrete pits, with height regime groundfloor+1... 4 floor, and monolithic and especially prefabricated reinforced concrete floors;
 - large panel structure, with groundfloor + 4 floors height regime;
 - structure made of monolithic reinforced concrete diaphragms and groundfloor + 4 floors height regime (in figure system - rigid or elastic ground floor, and cellular system and monolithic or prefabricated reinforced concrete floors;

- structure made of groundfloor + 4 floors reinforced concrete frames, with monolithic pillars, monolithic or prefabricated beams and floors made of prefabricated panels / semi-panels or superconcrete predals;
- structure from spatial elements.
- For high-rise buildings (maximum 16 floors)
 - structure from large panels with height regime groundfloor+ 7... 8floors;
 - monolithic reinforced concrete diaphragm structure with groundfloor+ 10floors height regime, in honeycomb or cellular system, same for groundfloor + 4floors;
 - structure made of reinforced concrete frames with height regime GF + 6... 14 floors, with monolithic pillars;
 - structure with central core and monolithic reinforced concrete pillars with groundfloor + 10 floors height regime with monolithic or prefabricated beams and floors.

The new residential buildings with load-bearing masonry structure and few levels, had a varied behavior at the earthquake of March 4, 1977, mainly, depending on the level in which a conformation and composition corresponding to the seismic loads were ensured and according to the degree of seismic intensity associated with the location.

In general, such buildings did not suffer significant damage, as long as the rules and principles of compliance and earthquake calculation were observed. In the situations in which these anti-seismic insurance measures were not observed, they suffered damages of varying severity, especially on the ground floor and the first floor, among which are mentioned:

- oblique cracks, especially in the longitudinal walls, located, usually, at the corners of the window and door openings, but also inclined open cracks, usually at 45° in one direction or in the shape of "X", in two directions, denoting breaking the masonry due to the action of the main efforts (stretching), and sometimes there was even the destruction of some masonry elements;
- horizontal cracks in the walls located mainly under the floor above the ground floor or at the lower and upper part of the masonry spans between the windows;

- long vertical cracks in the walls, sometimes along the entire height of the wall, usually following the cracks in the joints between the precasted elements of the floors (strips, semi-panels), but also in the window railings or at the intersection of transverse and longitudinal diaphragms, especially in buildings without belts or other horizontal connections and also due to local masonry defects;
- moving the walls vertically;
- dislocations and expulsions of masonry at the corners of the building;

Atypical cases of damage to buildings with load-bearing masonry structure:

- cracks at the intersections between the exterior and interior walls due to the fact that the masonry used at the exterior walls had a different format unlike the masonry for interior walls, resulting in a defective weaving at 3-4 rows which favored the initiation of cracks;
- cracks produced in the walls by the pushes caused by the terrace floor, which, not being sufficiently thermally insulated, were already deformed and cracked by temperature variations (they no longer fulfilled the role of rigid washer), and at the time of the earthquake, the cracks intensified at the same time, as the new fins began, the overall rigidity had decreased enough to lose its capacity as a rigid washer; this situation was encountered in buildings in Bucharest - Pajura, Giulesti, Drumul Taberei, etc. neighborhoods.

The new residential buildings with the structure of large panels behaved, generally well, not signaling significant damages to the structural elements, which would affect the stability and resistance of the buildings.

In isolated cases, there were damages such as: cracks in the monolithic areas between the panels, at the intersections of the walls, at the joints of the floor panels on the walls, cracks at 45° in lintels and also in some walls. In general, the cracks did not exceed openings of approx. 1 mm.

The new residential buildings with monolithic reinforced concrete diaphragm structure had a different behavior depending on the number of levels, the quality of execution, and the intensity of the seismic movement in the site. The buildings with low height regime (more rigid) with groundfloor+ 4floor, had a generally good behavior, but those with high height regime, more than 4 floors, had a less good behavior, noticing strong degradations. , including cases of partial collapses in Bucharest (an end portion of the block from Sos. Stefan cel Mare, corner with Lizeanu Street and an end section of the OD16 block from Bd. Pacii). Degradations have generally been located in areas such as: lintels and the base of diaphragms, including end bulbs.

The buildings with the structure in reinforced concrete frames, had an unfavorable behavior, in the case of those with high height regime, and the specific damages registered were at the level of columns and beams reinforcement buckling, etc.), but also at the level of non-structural elements (masonry and partition filling walls - cracks, cracks, collapses, etc.).

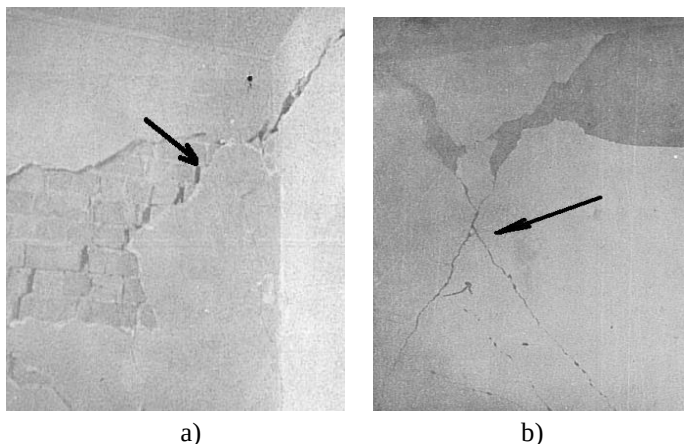


Figure 37 - a) Damage to load-bearing masonry walls; b) "X" shaped cracks in the reinforced concrete diaphragms [10]

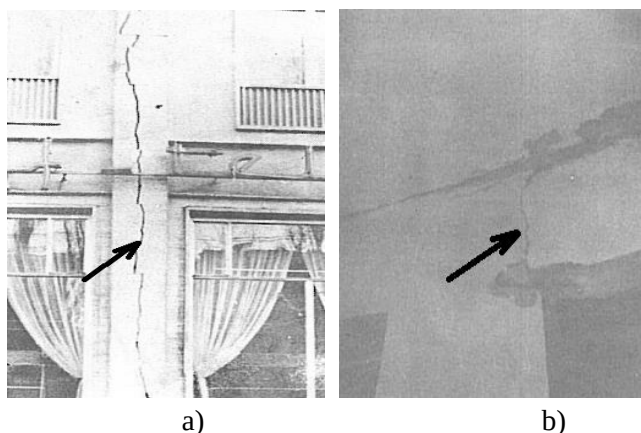


Figure 38 - a) Opening a joint in the facade; b) Breaking a beam in the area of the elevator house [10]

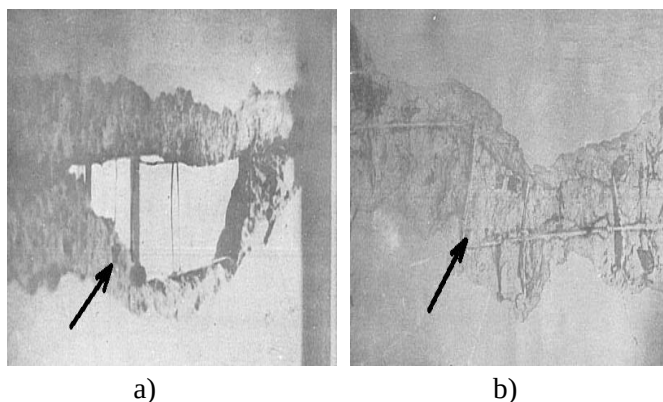


Figure 39 - a) Damages of a concrete diaphragm; b) Cracks and horizontal cracks with expulsion of the concrete coating layer to concrete diaphragms [10]

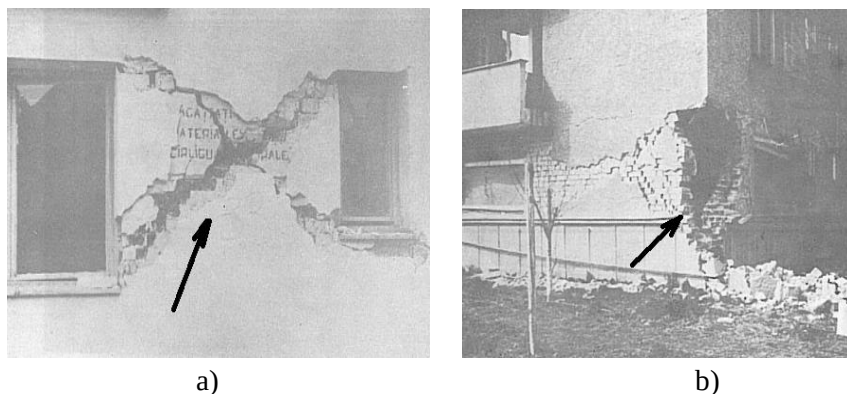


Figure 40 - a) Spindles for masonry washers; b) Damage to the exterior walls, there is a lack of concrete corner columns [10]

3.6.4 Behavior of new socio-cultural and administrative buildings

The new social - cultural and administrative buildings are of a varied functional diversity: buildings for collective accommodation (hotels, dormitories), medical buildings (hospitals), canteens, commercial buildings, central and local administration buildings, cultural - religious, buildings in the field of sports, etc. For these, were used in general, almost all construction systems adopted for residential buildings (load-bearing masonry, monolithic reinforced concrete diaphragms, reinforced concrete frames, etc.), as well as their combination (mixed structures).

In general, it can be mentioned that a better behavior was found compared to the old ones, an isolated case was that of the collapse of the MTTc Computing Center in Bucharest (old building). Regarding the damages, they were specific to the structural typologies, including the isolated situations of collapses.

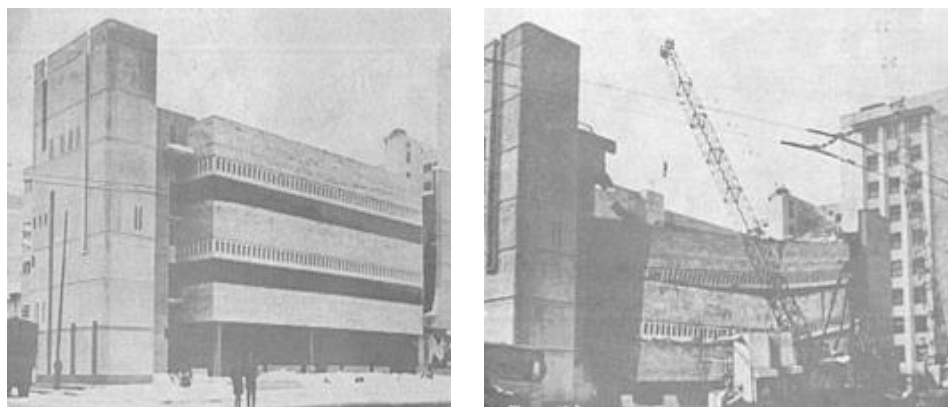


Figure 41 - Prabusirea cladirii Centrului de Calcul electronic MTTc, Str. Garii de Nord – Bucuresti; stap parter puternic avariat la partea superioara (sub capitel) [10]

3.6.5 Behavior of industrial, agro-zootechnical, hydrotechnical, transport and telecommunications constructions

The industrial constructions, from the point of view of the constructive composition, can be grouped in three big categories: ground floor halls, multi-storey buildings and special constructions. For halls were adopted as structural systems of: monolithic reinforced concrete, prefabricated, mixed and metallic. In general, these constructions had a good behavior, especially those with metallic structure, but there were isolated cases of structures that suffered specific damages (cracks, cracks, pillar ruptures, etc.), and even partial collapses (eg the company of chemical equipment Grivita Rosie - Bucharest).

The multi-storey industrial buildings (old and new) were made of monolithic / prefabricated and mixed reinforced concrete structures. Their behavior was also generally good, with isolated cases of specific damage being recorded, but no cases of collapsing.

Special constructions (silos, bunkers, tanks, water towers, cooling towers, chimneys, external trusses for overhead cranes and walkways for conveyor belts), generally behaved well, locally registering situations of significant damage to the old chimneys made of load-bearing masonry and even complete collapses, and at the water towers, they represent a special category of constructions, registering in their case, situations of significant damages and even complete collapses (5 cases, 4 around Bucharest and a case in Pleasa - Ploiesti).

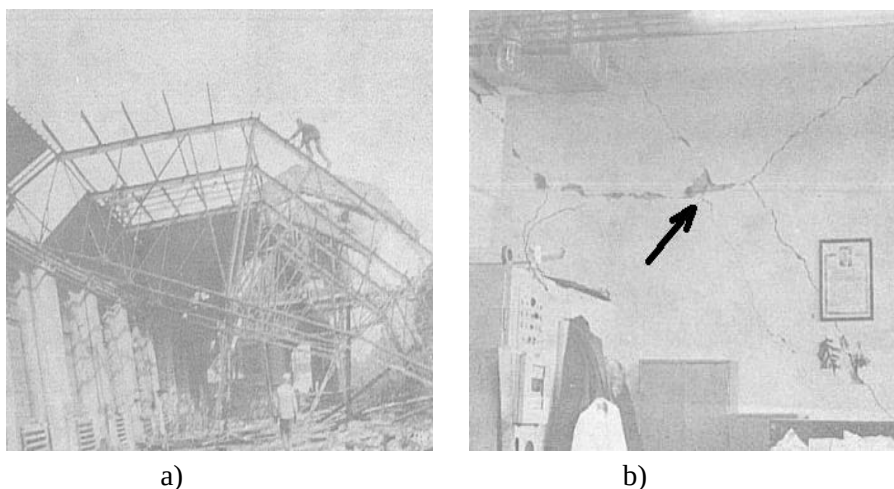


Figure 42 - a) Metal frame collapse - Petroleum equipment company, assembly hall - Prahova county;
b) Cracks in the interior masonry walls, multi-storey frame building b.a. - ICCE Bucharest [10]

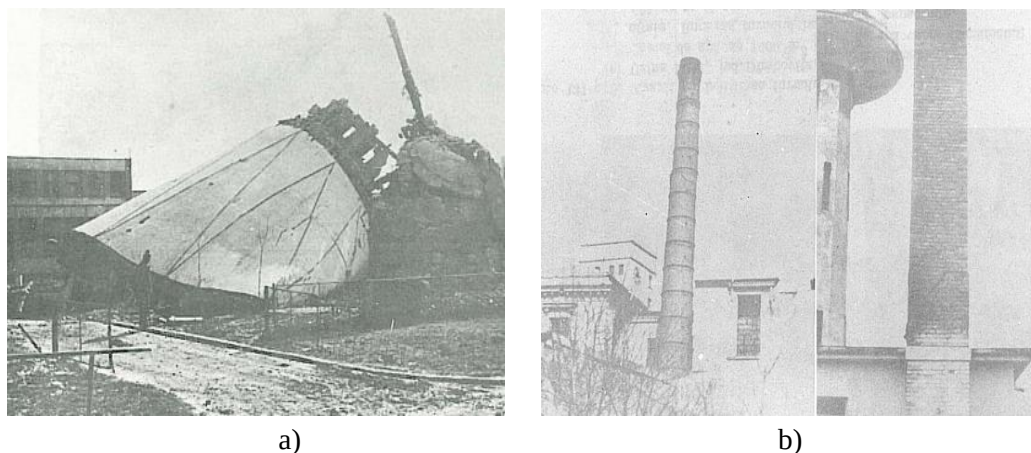


Figure 43 - a) Collapsed water castle, Kinescope Enterprise - Bucharest; b) Damages in the upper third of the chimneys in the masonry, Bucharest - Ilfov [10]

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