sciendo

Mathematical Modelling in Civil Engineering
Vol. 20-No. 3: 41-60-2025
10.2478/mmce-2025-0014

THE IMPACT OF VRANCEA MARCH 4, 1977 EARTHQUAKE ON THE BUILT ENVIRONMENT OF CRAIOVA

Alexandru Robert VLĂDUȚ – PhD student, Technical University of Civil Engineering of Bucharest
e-mail: robert.vladut@gmail.com

Radu VĂCĂREANU – PhD, Professor, Technical University of Civil Engineering of Bucharest
e-mail: radu.vacareanu@utcb.ro

Abstract: Considering the adverse effects of 1977 Vrancea earthquake in Craiova, in addition to the old single-family residential buildings that suffered significant damage, newly built collective housing blocks constructed between 1960 and 1975 also showed major structural issues. A total of 69 buildings comprising 121 sections were identified. Fortunately, no collective residential buildings collapsed. Craiova had the highest number of large residential buildings damaged after Bucharest. Craiova was not considered a seismic zone according to the 1963 seismic zoning code, and therefore the structural requirements and seismic design regulations were not incorporated into the design of its buildings. This changed in 1978 due to the new seismic design code enforced at that time, when the structural systems made of masonry walls were replaced by large prefabricated panels in residential buildings with a height regime of ground floor plus four stories (GF+4S). Unfortunately, for the buildings damaged by the March 4, 1977 earthquake, only partial repair and retrofitting works were carried out.

Keywords: seismic hazard; soil classes; empirical models; engineering parameters; seismological parameters; reinforced concrete; unreinforced masonry walls; vulnerability;

1. Introduction

This paper tackles the seismic risk of the residential building stock in the municipality of Craiova, with a particular focus on structures with a height regime of ground floor plus four stories (GF+4S). The selection of this building category is justified by the fact that approximately 50% of the city's population resides in such buildings, which renders them a strategic importance in the assessment of urban seismic risk.

The paper begins with an overview of seismic zoning in Romania, examined through the lens of the evolution of seismic demands in the design codes. It then addresses the impact of the March 1977 earthquake on the built environment of Craiova and Dolj County, with a particular focus on structural typologies of buildings with a ground floor and four stories (GF+4S), both prior to and following the seismic event.

To assess current seismic exposure, the study will utilize demographic and housing data from the 2011 census, information from the European Seismic Risk Model (ESRM 2020), as well as additional data gathered from various sources.

Although the scientific literature provides limited insight into the effects of the 1977 earthquake on Craiova and Dolj County, it is noteworthy that the number of damaged residential buildings in this region was the highest after Bucharest as shown in Figure 1.1 and 1.2 [1], underscoring the need for a comprehensive analysis.

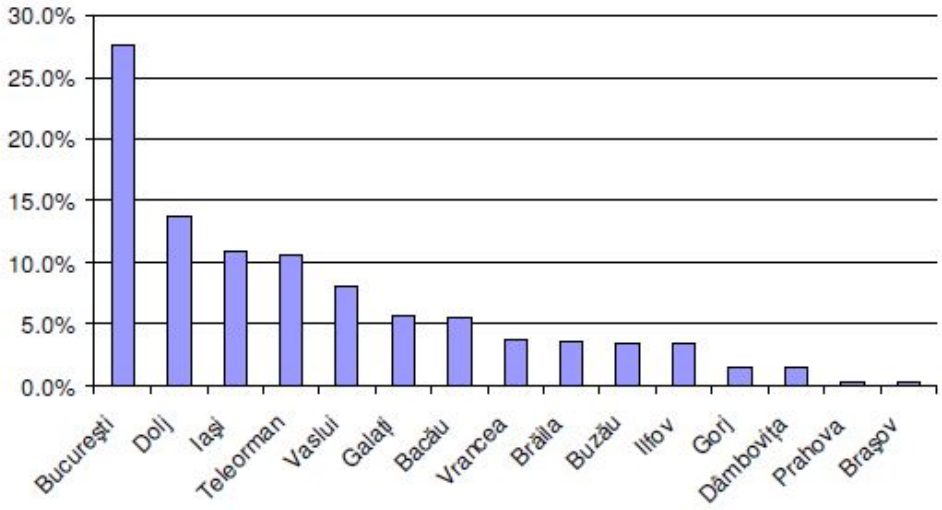

Fig.1.1 - The territorial distribution of residential buildings destroyed in the March 4, 1977 earthquake [1]

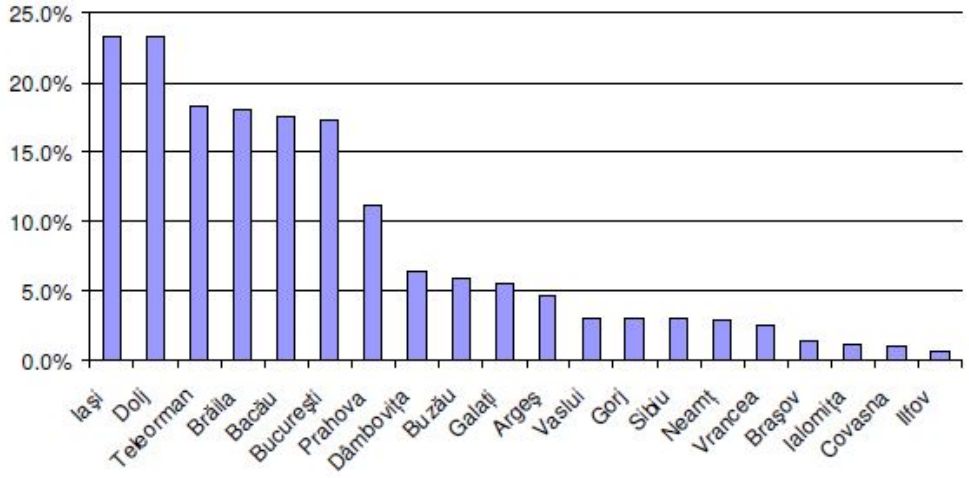

Fig.1.2 - Estimated Proportion of Damaged Residential Buildings by County in the March 4, 1977 earthquake [1]

2. Seismic Zoning of the Municipality of Craiova

Prior to the Vrancea earthquake of March 4, 1977, the city of Craiova was classified within macroseismic intensity zone VI, according to the seismic zoning maps in use at the time. Under this classification, seismic design was not required in structural design, except for buildings of special importance.

Earlier, under the Provisional Instructions of 1942, before the adoption of STAS 2923-52 [2], Craiova was considered part of the area exposed to Vrancea earthquakes. For this zone, designers were required to account for a seismic force equal to 5% of the total load (dead loads plus live loads).

Following the 1977 earthquake, seismic design codes were revised significantly. The updated seismic codes introduced peak ground acceleration (ag) values specific to Craiova, as well as corner period (TC) values used in spectral analysis for structural design.

These parameters are detailed in Table 2.1 of the applicable seismic codes issued after 1977, reflecting Craiova's reclassification into a zone with higher seismic hazard, with design implications for both new and existing structures.

Tabel 2.1

Seismic design code	Design values of peak ground acceleration, a_g (g)	Corner Period T_C (s)
P100-81	0.16	1.5
P100-92	0.16	1.5
P100-1/2006	0.16	1.0
P100-1/2013	0.20	1.0

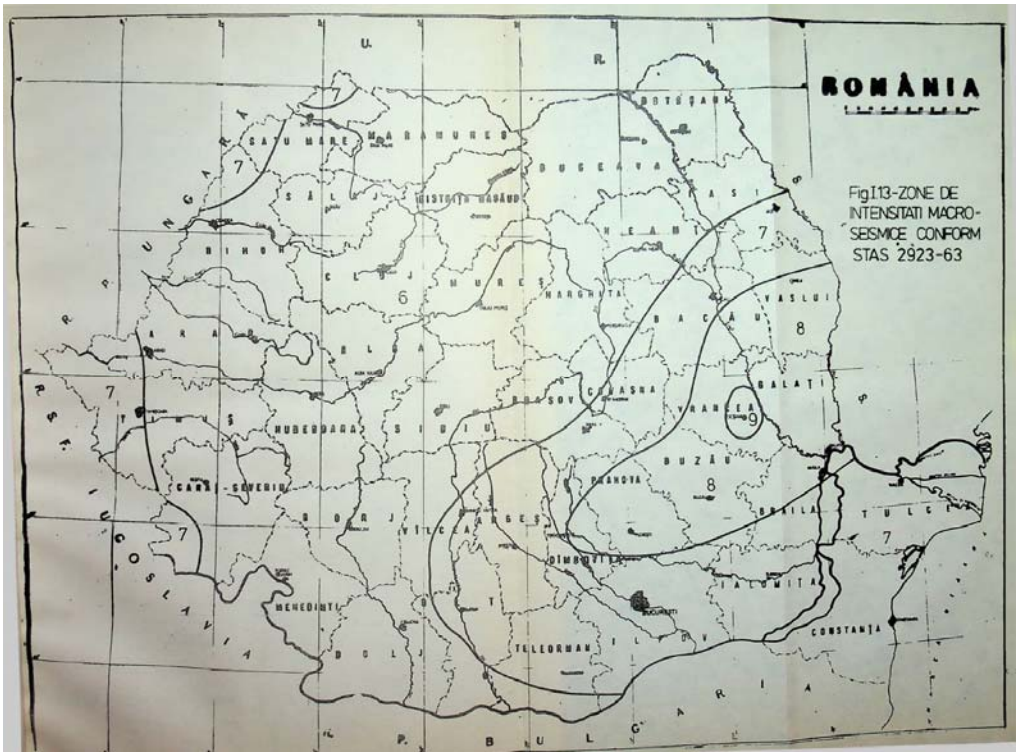

Fig. 2.1 - Macroseismic intensity zones as defined by Romanian Standard STAS 2923-63[3].

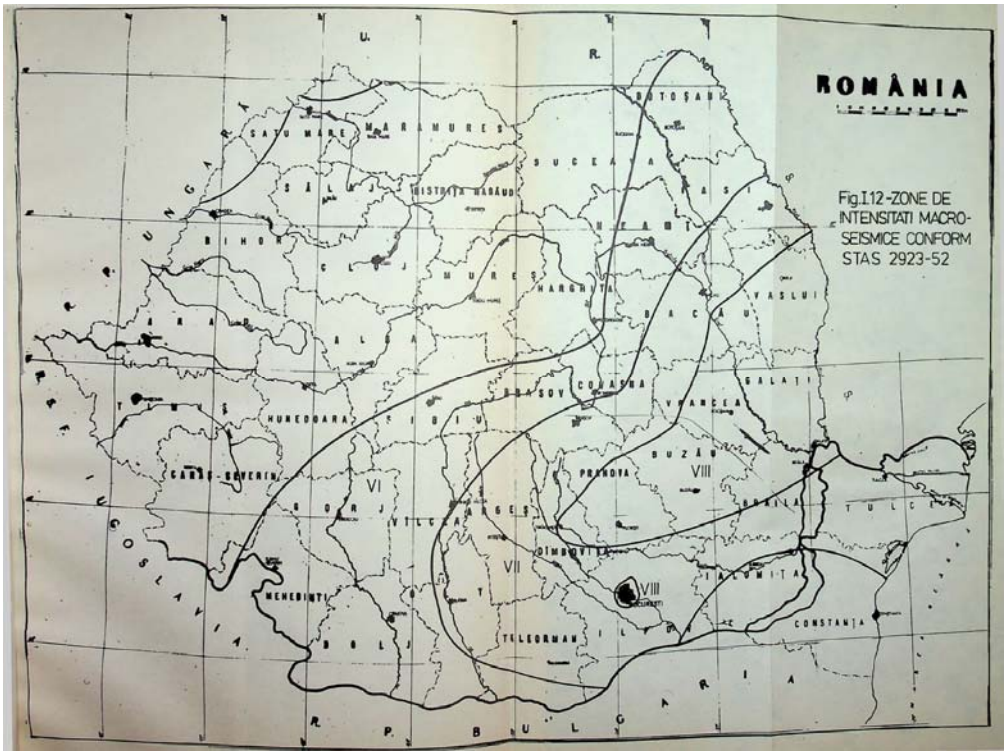

Fig. 2.2 - Macroseismic intensity zones as defined by Romanian Standard STAS 2923-52 [2].

Tabel 2.2

Evolution of seismic coefficients for different structural typologies [9-15]

Type of structure and height regime	Seismic design code						
	Before 1963	P13/63	P13/70	P100-78	P100-92	P100-1/2006	P100-1/2013
Unreinforced masonry **GF+4S**	5%	0%	0%	8.2%	10.2%	17.0%	22.1%
Confined masonry **GF+4S**	5%	0%	0%	8.2%	8.5%	12.0%	15.1%
Reinforced concrete frames **GF+4S**	5%	0%	0%	5.4%	6.8%	5.5%	6.3%
Reinforced concrete walls **GF+4S**	5%	0%	0%	8.2%	8.5%	8.1%	9.2%
Reinforced concrete frames **GF+8S**	5%	0%	0%	5.4%	6.8%	5.5%	6.3%
Reinforced concrete walls **GF+8S**	5%	0%	0%	8.2%	8.5%	8.1%	9.2%

3. The impact of the March 1977 earthquake on the built environment of Craiova

The Vrancea earthquake of March 4, 1977 (moment magnitude Mw = 7.4 and focal depth h = 94 km) significantly affected the built environment of the city of Craiova, despite an epicentral distance of over 250 km. The nationwide distribution of damage caused by the 1977 earthquake is shown in Figure 3.1 [4].

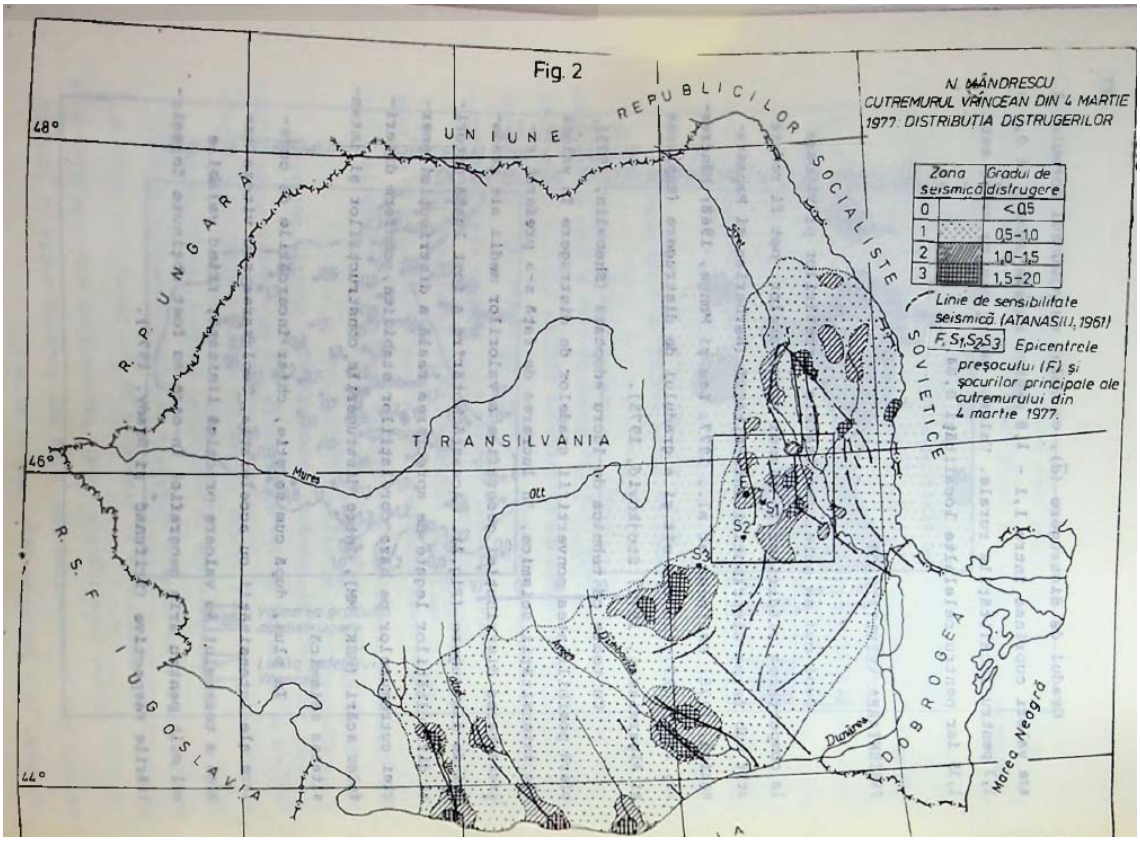

Fig. 3.1 - Distribution of damage from the March 4, 1977 earthquake [4]

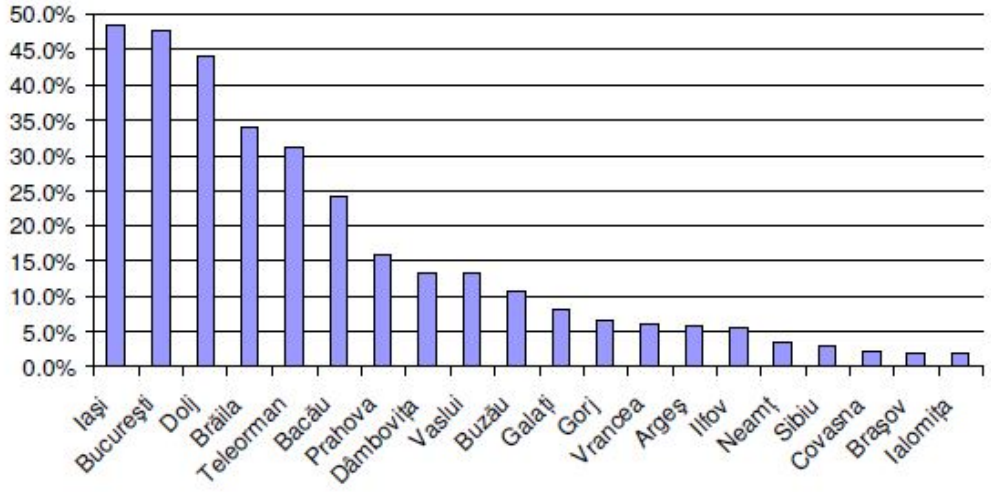

Fig. 3.2 - Percentage of residential buildings in each county that were affected by the March 4, 1977 earthquake (%) [1]

The earthquake lasted around 60 seconds in Craiova and destroyed most of the residential buildings, with their number surpassed only by those in Bucharest. The damage in Dolj County was immense, placing Dolj county third after Bucharest and Iași county in terms of the percentage of damaged buildings relative to the total number of existing buildings [1].

According to [5], the following seismic losses was reported:

- 40,675 buildings from the old housing stock were affected (13,290 in urban areas and 27,385 in rural areas) – of these, 537 buildings collapsed
- 28 apartment blocks with more than 4 stories (severely damaged)
- 151 apartment blocks with more than 4 stories (lightly damaged)
- 171 primary schools
- 83 kindergartens
- 29 high schools
- 19 school workshops
- 40 dormitories
- 14 orphanages and special schools
- 72 cultural centres
- 6 houses of culture
- 3 theatres
- 6 cinemas
- 39 enterprises totalling 106 workshop sections
- 72 livestock facilities
- 442 commercial units
- 3 hotels
- 134 churches
- 812 injuries and 41 deaths were recorded

The estimated damage amounted to nearly 200 milion lei (40 milion dollars) for the housing stock and approximately 150 million lei (30 milion dollars) for the industrial sector. Around 4,000 families were relocated [5].

Among the buildings with ground floor and four stories (GF+4S) height regime, 28 apartment blocks were severely damaged, while another 151 sustained light damage. Most of the heavily affected buildings followed the GF +4 typology and featured a structural system consisting of unreinforced masonry walls. The floor slabs were made of prefabricated elements supported by reinforced concrete beams. Although vertical confinement columns were present in some sections, they were only constructed up to the first floor, as the city of Craiova had not been classified as a seismic risk zone. This building typology was widespread throughout the city, yet damage was concentrated primarily in the Valea Roșie and Piața Gării districts.

The central area of Craiova, predominantly consisting of single-family houses with ground floor (GF) and ground floor and one story (GF+1S), was among the most severely affected, recording the highest number of damaged buildings. This was largely due to the very old building stock, characterized by poor-quality construction materials. Most of these structures were unreinforced masonry buildings with wooden floor slabs.

Major damage included cracks in masonry piers, X-shaped fissures, corner blowouts, and similar structural failures. Fortunately, no buildings with a height regime of GF+4S or higher collapsed. Although GF +4S masonry buildings were widespread throughout Craiova, they were severely affected in two districts and lightly damaged in one [6-8].

Fig. 3.3 - GF+4 Masonry Buildings Severely Affected by the March 4, 1977 Vrancea Earthquake [8]

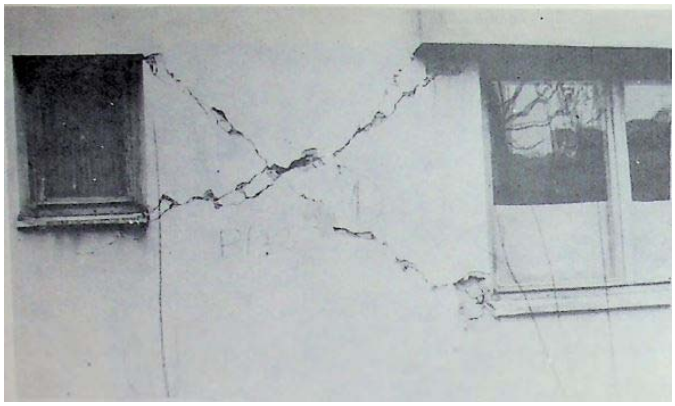

Fig.3.4 - Masonry wall at the ground floor of a GF+4 building [8]

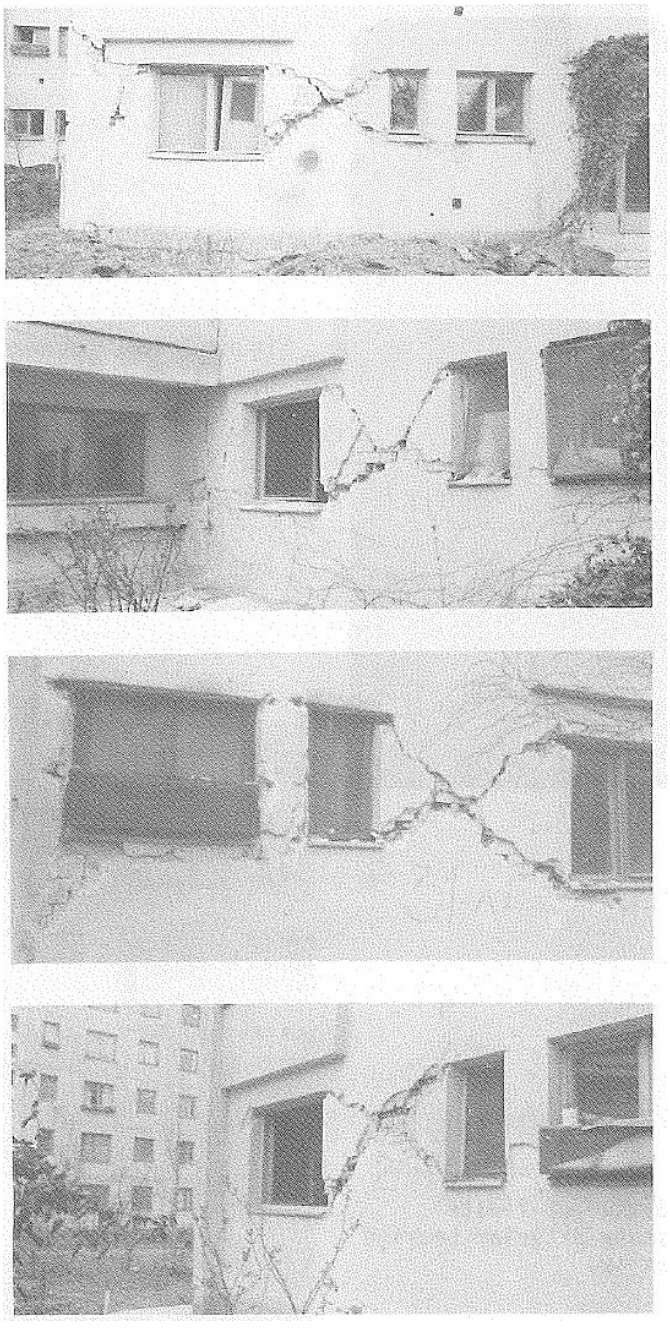

Fig.3.5 - Masonry wall at the ground floor of G+4 buildings [8]

The buildings were identified based on the elements present on the facade in the Valea Roșie district, totalling 31 buildings with the same characteristics.

Fig.3.6 - Buildings in the Valea Roșie district – 1975

Fig. 3.7 - Damaged buildings in the Valea Roșie District

Also from the Valea Roșie district, there is a unique photo showing a GF+10S building affected by the earthquake, with a horizontal crack running across a wall on the ground floor.

Fig. 3.8 - GF+10E Building Damaged in the Valea Roșie District [8]

Another district where GF+4S masonry buildings were severely damaged was Piața Gării. In blocks H, A, and K, the masonry walls were cracked such as *"We could see our neighbours through the cracks in the walls."* [5]. Unfortunately, no photographs of these buildings taken immediately after the 1977 earthquake are available. Their floor plans follow an H-shaped layout. A total of 18 such buildings were identified in the area surrounding Craiova's train station.

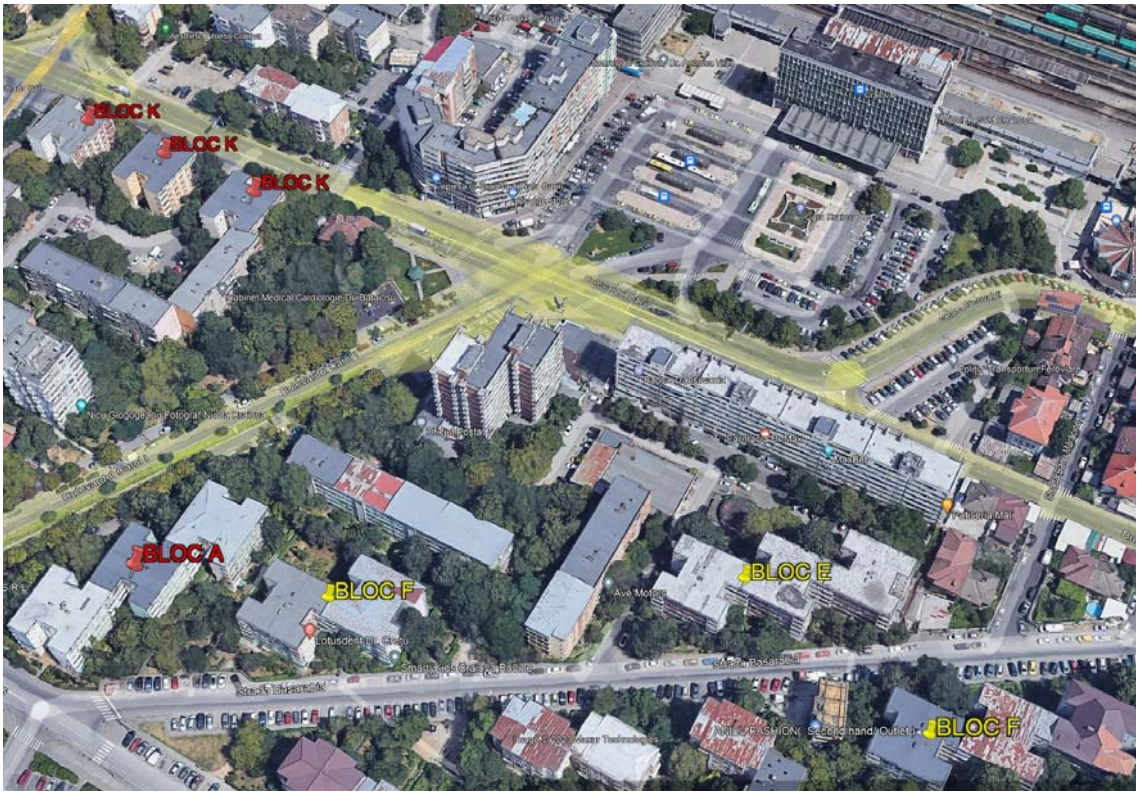

Fig. 3.9 - Typology of Damaged Buildings in the Piața Gării District

Fig. 3.10 - Tie rods on the exterior wall of Block A

Significant damage occurred both in the centre of Craiova and in the peripheral neighbourhoods, where the built environment was old and construction materials lacked reinforced concrete.

Fig. 3.11 - Damaged buildings in the central area of Craiova [5]

Other affected buildings included cultural institutions such as the University, the Prefecture building, Casa Baniei, museums, churches, schools, and high schools.

Fig. 3.12 - Casa Băniei after the March 1977 earthquake [5]

Fig. 3.13 - Casa Băniei after the November 1940 earthquake

The study [16] mentions a building in Craiova that experienced a particularly unusual failure. In structures with “spatial box” systems, the columns between the prefabricated concrete boxes were reinforced with post-tensioning. This reinforcement was anchored at the foundation level into the bands of the slab above the basement. In one such building under construction, a failure of the anchorage was observed at the slab above the first floor.

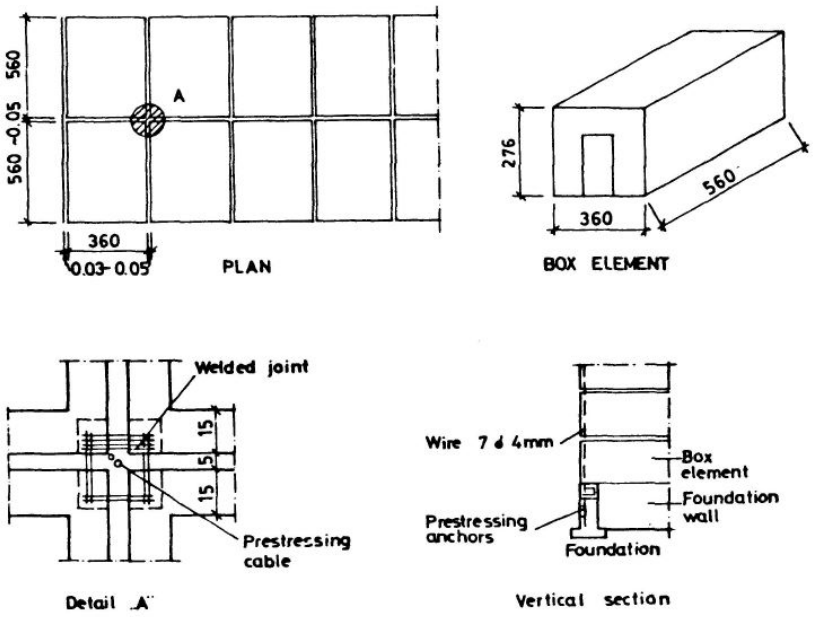

Fig. 3.14 - Prefabricated blocks in Craiova known as "Spatial Boxes" assembled through vertical post-tensioning – execution details [16]

Fig. 3.15 - "Spatial Boxes" produced at the Prefabricated Components Factory in Brașov

The highest number of casualties occurred at the Garment Factory, a slender GF+6S building with tall floors designed to allow natural ventilation. The building comprises three sections connected by joints, with a total length of approximately 140 meters. During the evacuation, panic among the large number of female workers rushing down the main staircase caused the handrail between the 3rd and 2nd floors to collapse, resulting in people falling down the stairwell. Amid the chaos caused by the earthquake and the railing collapse, three individuals jumped out of windows. In total, 14 people lost their lives and over 39 sustained serious injuries. The building itself did not suffer significant structural damage [5].

Fig. 3.16 - The Garment Factory Building

4. Structural Typologies for GF+4 Buildings

4.1 Buildings made before 1977

The distribution of structural types for buildings up to G+4S in height is presented in [17]. The proportions for the year 1970 are illustrated in Figure 4.1. It can be noticed that two-thirds of the buildings constructed in 1970 had unreinforced masonry structures, while the remainder were built using large-panel systems. The proportion of frame structures was notably low.

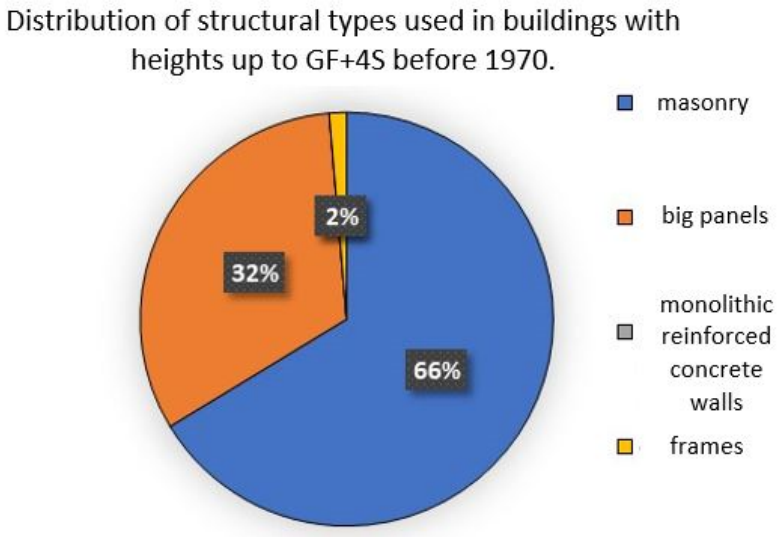

Fig. 4.1 - The proportion of different types of structural systems for buildings with a height regime of up to ground floor plus four stories (GF+4S) in the year 1970 [17]

Analysing the design projects for GF+4S buildings, four building typologies built in Craiova can be identified:

A. Buildings with masonry structures
B. Buildings with large-panel structures
C. Frame-structured buildings - very few, considered experimental and still in the testing phase

4.2 Buildings built after 1977

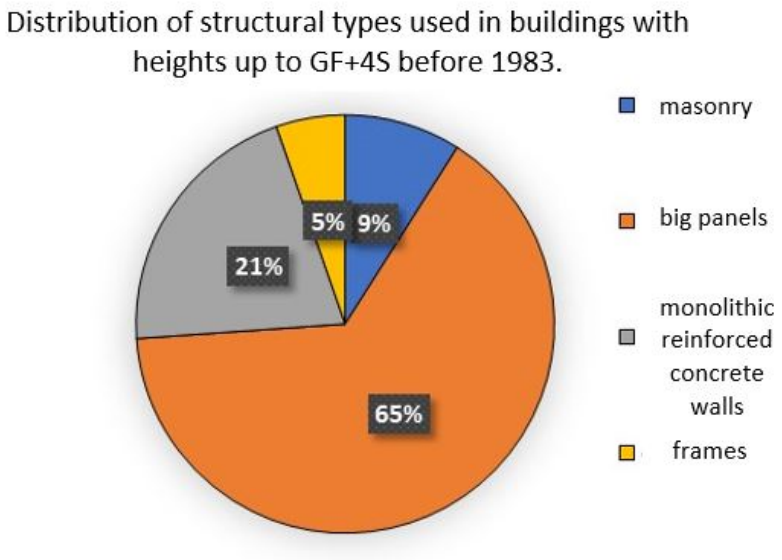

Fig. 4.2 - The proportion of different types of structural systems for buildings with a height regime of up to ground floor plus four stories (GF+4S) in the year 1983 [17]

From Figure 4.2, it can be observed that two-thirds of the buildings constructed in 1983 featured large-panel structures. Among the remaining structural types, the most used were those with cast in place reinforced concrete walls, while the share of masonry and frame structures was below 10%.

Following the damage recorded during the 1977 earthquake, the design of GF+4S buildings in Craiova was modified as follows:

A. Masonry-structured buildings were no longer built on a large scale. For those already under construction, the reinforcement of confinement columns and the dimensions of the bands were increased. The confinement columns were extended along the full height of the building, up to the 4th floor.
B. Large-panel structures became the primary construction system for GF+4S buildings.
C. “Spatial box” buildings - a standard design developed in Craiova at the prefabricated components factory - were built extensively throughout the city.
D. Frame-structured buildings were constructed mainly in the central area of Craiova.

5. Seismic Exposure of Buildings in the Municipality of Craiova

5.1 The 2011 Census of Buildings and Dwellings

The data regarding the number of residential buildings obtained from the 2011 census are presented in Figures 5.1 to 5.3, categorized by building height, seismic code level, and construction material.

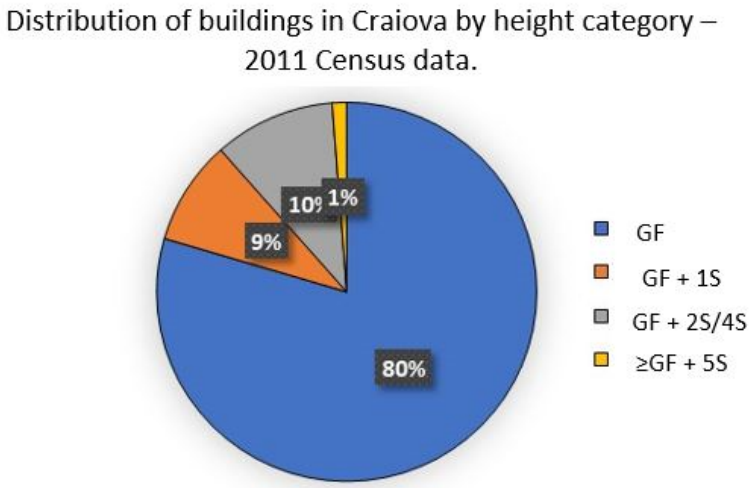

Fig. 5.1 - Distribution of buildings in Craiova by height regime based on data collected during the 2011 census.

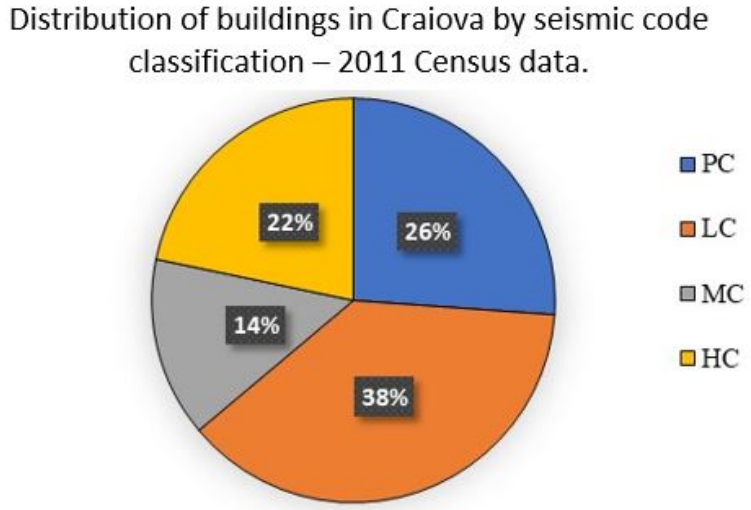

Fig. 5.2 - Distribution of buildings in Craiova according to seismic code level, based on data collected during the 2011 census.

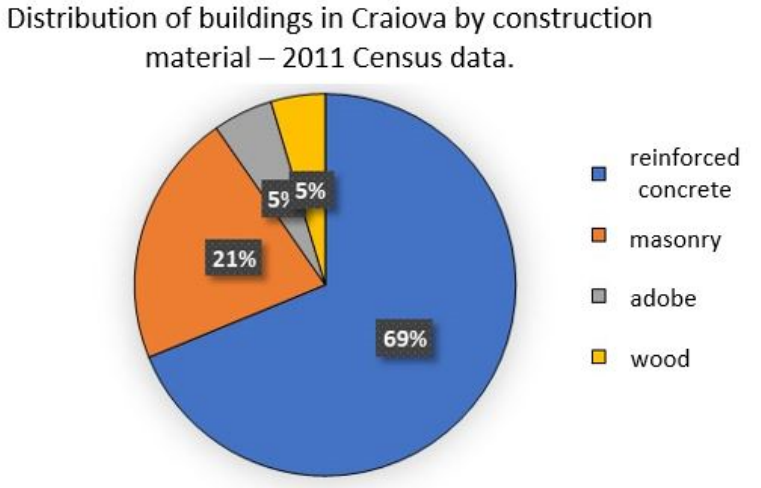

Fig. 5.3 - Distribution of buildings in Craiova by construction material, based on data collected during the 2011 census.

The years proposed for differentiating buildings based on seismic code level are [21]:

- No seismic code – before 1963
- Low-level seismic code – between 1963 and 1977
- Moderate seismic code – between 1978 and 1992
- Advanced seismic code – after 1992

An analysis of data collected during the 2011 census highlights the following:

- 94% of GF+4S buildings in the municipality of Craiova have reinforced concrete structures, while the remaining buildings feature masonry structures with reinforced concrete floor slabs.
- 98% of GF+4S buildings in Craiova were constructed during two key periods: between 1961 and 1977 (28%) and between 1978 and 1992 (72%). Consequently, these buildings can be classified as either designed under a low-level seismic code (pre-1977) or under a moderate-level seismic code (post-1977) [22-23].

5.3 Proposed Exposure Model

By combining data from the 2011 census, the exposure model by [18-20], and the findings of [17] and [22-23] an exposure model can be developed for G+4S residential buildings in the municipality of Craiova.

Figure 5.4 presents the distribution of GF+4S residential buildings in Craiova based on seismic code level.

The structural typology is shown as percentages in Table 5.1 and as building counts in Table 5.2, categorized by seismic code level.

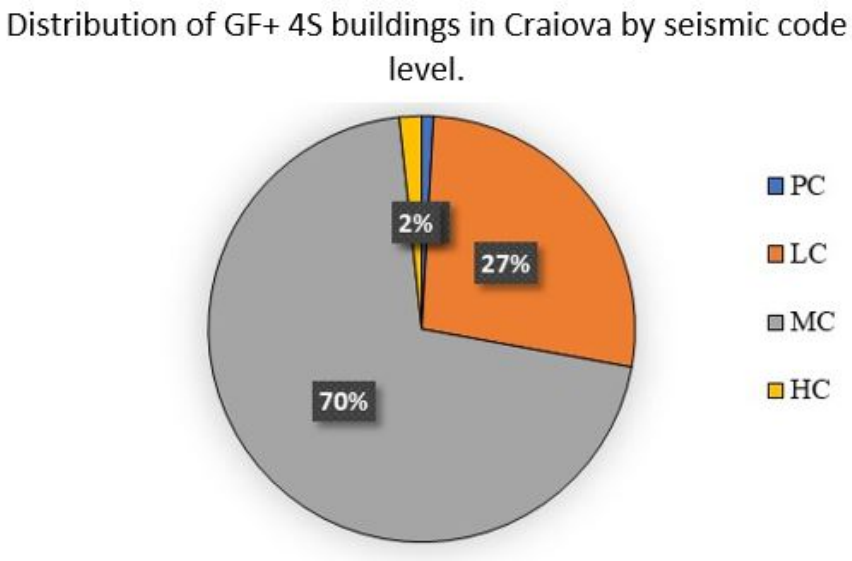

Fig. 5.4 - Proposed model: Distribution of P+4S buildings in Craiova according to seismic code level.

Tabel 5.1

Proposed Exposure Model for GF+4 Buildings in Craiova Based on Structural System – Percentage Distribution

Structural system	Large-panel buildings	Frame buildings	Masonry buildings	High-frame buildings
Unconfined masonry with wooden floor slabs	100%	0%	0%	0%
Unconfined masonry with reinforced concrete floor slabs	0%	60%	0%	0%
Confined masonry	0%	0%	10%	0%
Reinforced concrete frames	0%	5%	5%	80%
Monolithic reinforced concrete walls	0%	10%	20%	20%
Large panels	0%	25%	65%	0%

Tabel 5.2

Proposed Exposure Model for GF+4S Buildings in Craiova by Structural System – Number of Buildings

Structural system	Large-panel buildings	Frame buildings	Masonry buildings	High-frame buildings
Unconfined masonry with wooden floor slabs	21	0	0	0
Unconfined masonry with reinforced concrete floor slabs	0	384	0	0
Confined masonry	0	0	167	0
Reinforced concrete frames	0	32	84	32
Monolithic reinforced concrete walls	0	64	334	8
Large panels	0	160	1086	0

6. Conclusions

Following the assessment of seismic exposure for buildings and dwellings in the municipality of Craiova, with a focus on GF+4S buildings and based on available data, the following observations and conclusions can be drawn:

- During the 1977 earthquake, in addition to the old single-family residential buildings that suffered significant damage, newly built collective housing blocks constructed between 1960 and 1975 also showed major structural issues.
- Craiova was not considered a seismic zone according to the 1963 seismic zoning code, and therefore the structural requirements and seismic design regulations were not incorporated into the design of its buildings. This changed starting in 1978, when the structural systems made of masonry walls were replaced by large prefabricated panels in residential buildings with a height regime of ground floor plus four stories (GF+4S)
- A total of 69 buildings comprising 121 sections were identified. Fortunately, no collective residential buildings collapsed. Craiova had the highest number of large residential buildings damaged after Bucharest.
- The very high percentage of damaged buildings in the Valea Roșie neighbourhood is also since the foundation soil is sensitive to moisture - macroporous soils [4].

- In 1970, most of the buildings (two-thirds) up to GF+4S in height had masonry structures. Approximately 400 GF+4S buildings were built before 1977. By 1983, most buildings of this height were constructed using large-panel systems, with the share of masonry structures dropping below 10%.
- Regardless of the construction period (before or after 1977), the proportion of GF+4S frame-structured buildings never exceeded 5%. Therefore, the exposure model by [18-20], which attributes nearly half of Craiova's GF+4S buildings to frame structures, appears to significantly overestimate this category.
- Another issue identified in [18-20] model concerns GF+4S masonry buildings. The model assumes all such buildings have confined masonry structures; however, based on an analysis of Romanian design codes before and after 1977, only buildings constructed after 1977 can be classified as confined masonry. Those built before 1977 should be considered unreinforced masonry structures.
- Finally, by combining data from the 2011 census, [18-20] exposure model and [17], an exposure model has been developed for GF+4S residential buildings in the municipality of Craiova.

References

[1] Emil-Sever GEORGESCU, Antonios POMONIS (2008), The 14th World Conference on Earthquake Engineering, Beijing, China - The Romanian earthquake of March 4, 1977 revisited: new insights into its territorial, economic and social impacts and their bearing on the preparedness for the future

[2] Comisia de Standardizare (1952) STAS 2923-52 – Sarcini în construcții. Zone de intensități macroseismice, București, România.

[3] CSCAS (1963) P13-63 Normativ condiționat pentru proiectarea construcțiilor civile și industriale din regiuni seismice, București, România.

[4] Mândrescu N (1979) Cutremurul din 4 martie 1977 – Distribuția distrugerilor. În: Cornea I, Radu C (ed.) Cercetări seismologice asupra cutremurului din 4 martie 1977, Centrul de Fizica Pământului și Seismologie, pp. 371-388.

[5] Trita L., Gavrila V., Babalau N, (1978) Noaptea cea mai lunga a Craiovei. Editura Scrisul Romanesc, Craiova.

[6] ICCPDC (1978) Cutremurul din România din 4 martie 1977 și efectele sale asupra construcțiilor. Sinteza monografiei.

[7] The Romania Earthquake Survey Group of Experts and Specialists Dispatched by the Government of JapanSurvey Report, June 1977, Japan International Cooperation Agency

[8] Fattal, G., Simiu, E., Culver, Ch., (1977). Observation on the behaviour of buildings in the Romanian earthquake of March 4, 1977. US Dept of Commerce, Sept 1977, NBS Special Publication 490.

[9] ICCPDC (1975) Normativ privind alcătuirea și calculul structurilor de zidărie București, România.

[10] ICCPDC (1978a) P100-78 Normativ pentru proiectarea antiseismică a construcțiilor de locuințe, social-culturale, agrozootehnice și industriale, București, România.

[11] ICCPDC (1985) Normativ privind alcătuirea, calculul și executarea structurilor de zidărie București, România.

[12] MCI (1970) P13-70 Normativ pentru proiectarea construcțiilor civile și industriale din regiuni seismice, București, România.

[13] MLPAT (1992) Normativ pentru proiectarea antiseismică a construcțiilor de locuințe, social-culturale, agrozootehnice și industriale, București, România.

[14] MDRAP (2006) P100-1/2006 - Cod de proiectare seismica – partea I – prevederi de proiectare pentru clădiri, București, România.

[15] MDRAP (2013) P100-1/20013 - Cod de proiectare seismica – partea I – prevederi de proiectare pentru clădiri, București, România.

[16] Velkov, Miodrag (1978) Behaviour of large panel building during the Romania earthquake of March 4, 1977

[17] Avram C (1987) Betonul armat în România. Ed. Tehnică, București, România

[18] Crowley H, Despotaki V, Rodrigues D, et al (2020) Exposure model for European seismic risk assessment. Earthquake Spectra 36:252–273.

[19] Crowley H, Despotaki V, Silva V, et al (2021a) Model of seismic design lateral force levels for the existing reinforced concrete European building stock. Bull Earthquake Eng 19:2839–2865.

[20] Crowley H, Dabbeek J, Despotaki V, Rodrigues D, Martins L, Silva V, Romão X, Pereira N, Weatherill G, Danciu L (2021b) European Seismic Risk Model (ESRM20). EFEHR Technical Report 002 V1.0.0, https://doi.org/10.7414/EUC-EFEHR-TR002-ESRM20

[21] Lungu D, Aldea A, Arion C, Cornea T, Vacareanu R (2002) Risk-UE, WP1: European distinctive features, inventory database and typology. In: Lungu D, Wenzel F, Mouroux P,

[22] Văcăreanu R, Pavel F, Aldea A, Arion C, Neagu C (2015a) Elemente de analiză a hazardului seismic. Editura Conspress, București, ISBN 978-973-100-386-3.

[23] Pavel F, Vacareanu R, Arion C, Aldea A (2022) New Insights on the Seismic Exposure and Vulnerability of Structures in Romania. In: Vacareanu R, Ionescu C (eds) Progresses in European Earthquake Engineering and Seismology. Springer International Publishing, Cham, pp 197–211.