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An Updated Perspective of the Impact of the 1940 Vrancea Earthquake on Design and Construction Practices in Romania

Florin Pavel

Department of Reinforced Concrete Structures, Technical University of Civil Engineering Bucharest, Bd. Lacul Tei, 122-124, Sector 2, 020396 Bucharest, Romania; florin.pavel@utcb.ro

Abstract: This study presents an updated view of the effects of the 1940 Vrancea earthquake. Recently compiled studies in the literature from the time of the event, as well as other studies, present the opportunity to gain additional and relevant information regarding this large-magnitude event. The effects of this earthquake on various locations in Romania are compared to those observed after the subsequent large Vrancea earthquake of 1977. An assessment of the economic losses caused by the seismic event is also attempted. The seismic vulnerability of some building typologies commonly used before 1940 is assessed by employing the earthquake damage data and the well-known macroseismic method. The impact of this event on the design and construction practices in Romania is evaluated using the collected information as well. Finally, the policy of repair and strengthening of buildings applied after the event is also discussed, and case studies are presented.

Keywords: seismic damage; macroseismic intensity; peak ground acceleration; structural typology; seismic vulnerability; strengthening of buildings

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1. Introduction

The Vrancea 1940 earthquake is, according to the ROMPLUS catalogue of the National Institute of Earth Physics in Romania (NIEP), the largest earthquake which has occurred in this seismic source in the XX-th century and is the second largest in terms of magnitude after the 1802 event. In this study, we make use of a significant number of newly compiled references in order to increase the level of knowledge regarding this event from the point of view of its effects and its impact on construction designs and practices. A discussion regarding the various models for Vrancea intermediate-depth seismic zone can be found in the studies by Ismail-Zadeh et al. [1] and Petrescu et al. [2]. The source scaling of various large-magnitude Vrancea intermediate-depth earthquakes is analysed by Gusev et al. [3].

The re-assessment of the effects of various earthquakes (especially historical ones) is a very important topic since it allows for a better and thorough understanding of the impact of a particular earthquake and can provide useful information for a seismic risk assessment. For instance, Ambraseys and Finkel [4] examined the impact of the 1912 Marmara Sea earthquake, which was one of the largest earthquakes which occurred in the Balkan region in the XXth century. In the paper by Ambrseys [5], a comparison of the effects of the 1894 and 1999 earthquakes in the western part of Turkey is presented. Ambraseys and Bilham [6] performed a re-evaluation of the impact of the Great Assam (India) earthquake of 1897. The sized and locations of several of the largest 19th-century earthquakes in the San Francisco Bay area were re-assessed by Tuttle and Sykes [7]. Hough et al. [8] and Hough and Hutton [9] revisited and reassessed the magnitudes of the 1811–1812 New Madrid earthquakes and the 1872 Owens Valley earthquake based on their effects. In the study by duPont and Noy [10], a re-evaluation of the impact of the Kobe 1995 earthquake is shown. M. R. Sbeinati et al. [11] performed an evaluation of the effects of various earthquakes from Syria, which occurred in the 1365–1900 period. Georgescu and Pomonis [12] and Georgescu and Pomonis [13] performed various re-assessments of the impact of the 1977 Vrancea (Romania) earthquake. Martin et al. [14] presented a re-assessment of the 1907 Sumatra earthquake based on both its macroseismic effects and various tsunami observations. Hough [15] performed a reassessment of the felt effects of the 8 February 1843 Lesser Antilles earthquake and showed an example of an initially underestimated seismic event. Buforn et al. [16] discussed the 1969 Saint Vincent Cape earthquake and performed comparisons with the previous large-magnitude 1755 event.

Another important issue regarding earthquakes which happened before the instrumental era or when the number of strong ground motion instruments was extremely limited is the estimation of ground motion amplitudes. Various solutions for ground motion estimations have been proposed in the literature using both seismological parameters as well as macroseismic observations. Since no ground motion was recorded during this event, a discussion regarding an estimation of the ground motion amplitudes during the Vrancea intermediate-depth seismic event of November can be found in the studies by Pavel and Vacareanu [17] and Pavel and Vacareanu [18]. In the latter study, the ground motion amplitudes were derived starting from the macroseismic intensities of the event, while in the former study, the procedure involved both ground motion prediction equations as well as stochastic ground motion simulations. In the case of Bucharest, for instance, the estimated ground motion amplitudes were larger than the ones recorded during the Vrancea 1977 seismic event.

The 1940 event is best remembered for causing the collapse of the tallest reinforced concrete building in Bucharest (at that time), namely the Carlton building [19,20], and for the total collapse of almost all of the buildings in the small city of Panciu, located near the epicentre area of the earthquake [21].

Newly discovered studies in the literature from the time of the earthquake allow for a more thorough description and analysis of its effects. Consequently, the main objectives of this study are as follows:

- To re-evaluate the effects (on both the building stock and the population) of the 1940 Vrancea earthquake by considering newly available studies in the literature;
- To compare the effects of the Vrancea 1940 and 1977 earthquakes (the two largest earthquakes occurring in this seismic region in the XX-th century) by focusing on distant counties (Dolj and Constanta), on counties situated near the Vrancea seismic source (Prahova and Vrancea) and, finally, on counties located in the back-arc region with respect to the same seismic source (Brasov and Sibiu);
- To conduct an assessment of the macroseismic intensity in Bucharest;
- To evaluate the seismic vulnerability of some building typologies that were commonly used before 1940 (e.g., high-rise reinforced concrete residential buildings in Bucharest and low-rise masonry structures in Barlad);
- To conduct an assessment of the economic losses;
- To present a discussion regarding the impact of the earthquake on design and construction regulations;
- To evaluate the repair and strengthening policy applied to the buildings in the aftermath of the earthquake.

All of the objectives of this paper bring about additional relevant information regarding this event, which represented a major surprise at that moment, as more than 100 years had passed since the previous large Vrancea earthquake (the 1838 event).

2. Effects of the Vrancea 1940 Earthquake

A detailed evaluation of the macroseismic intensities for this event, as well as for other Vrancea intermediate-depth earthquakes, can be found in the paper by Kronord et al. [22]. Other macroseismic intensity maps of this event have been proposed by Atanasiu and Kräutner [23] or Radulescu [24].

Liquefaction (which can be used in order to constrain ground motion amplitudes) in sites (situated in the valley of some rivers in the eastern part of Romania) where the same phenomenon occurred as a result of the 1977 earthquake was noticed by some researchers [25]. However, the territorial extent of this phenomenon cannot be assessed based on the available information. The impact of the 1940 event on embankment dams, which may be significantly affected during large earthquakes (as for instance in the recent February 2023 earthquakes [26]), also cannot be evaluated based on the current information.

2.1. Brief Description of Building Typologies Encountered in 1940 in Romania

A brief description of the building typologies commonly encountered in Romania (with emphasis on Bucharest) at the time of the earthquake allows for a better understanding of its effects. It has to be emphasized from the beginning that the gross majority of buildings at that moment were non-engineered structures. It was only in 1936 (four years before the earthquake) that the design of structures by specialized structural engineers was imposed in Bucharest because of a collapse of a temporary stand located in Bucharest.

The introduction of reinforced concrete as a construction material occurred in Romania in 1904 when it was first used for a slab [27]. Until 1912, when the first building with an RC skeleton (columns and beams) was built, the use of this material was limited to slabs. In 1930, the first high-rise (more than eight stories) residential buildings in Bucharest with a reinforced concrete structure were built, and by 1940, more than 200–300 such structures were constructed [27].

Consequently, the main structural typologies commonly encountered in Romania were as follows:

- Single-story structures made of local materials (depending on the geographical area, the walls were made using various construction techniques);
- Two-story masonry structures with timber flooring (commonly found in all small cities, generally also used for commercial purposes);
- Masonry structures (between two and six stories) used for residential purposes (found only in large cities), with slabs that were either flexible or rigid (various solutions including masonry and reinforced concrete were commonly encountered);
- Reinforced concrete structures for medium- and high-rise buildings (only in Bucharest), where the structural systems consisted of RC beams and columns placed based on architectural layouts.

Examples of the above-mentioned typical structural typologies located in Bucharest are given in Figure 1. It can be observed that their current states from the point of view of maintenance and current repair works are not adequate at all. Figure 2 shows the typical structural layout of a high-rise reinforced concrete building that was constructed before 1940 in Bucharest [28]. Other examples of typical low-rise structures located in Bucharest are shown in Figure 3.

Figure 1. *Cont.*

Figure 1. Typical high-rise structural typologies used before 1940 for residential buildings in Bucharest.

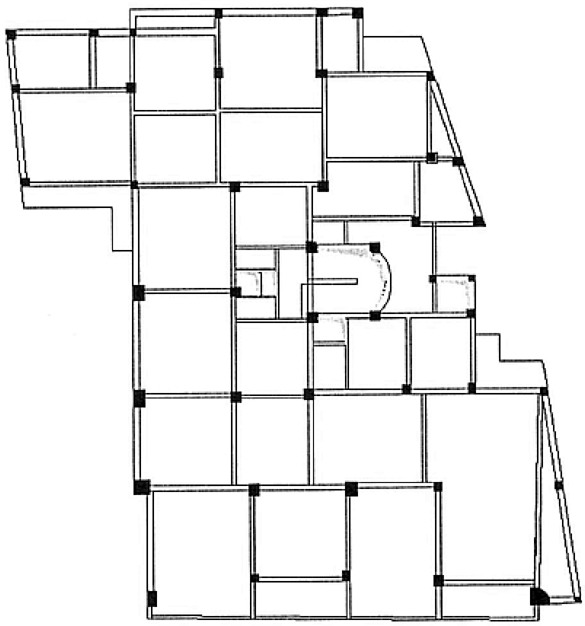


Figure 2. Typical layout of high-rise reinforced concrete structure built before 1940 in Bucharest [28].

Figure 3. *Cont*.

Figure 3. Typical low-rise structural typologies used before 1940 for residential buildings in Bucharest.

Figure 3 illustrates some common structural typologies for low-rise buildings with unreinforced masonry structures that were built before 1940.

2.2. *Representative Earthquake Damage*

Some photos showing the damage in various publications from the time of the event highlight both the effects and the common structural typologies described previously. Figure 4 shows the damage sustained by unreinforced masonry buildings located in Panciu (near the earthquake epicentre), where 338 buildings sustained heavy damage or collapsed [29].

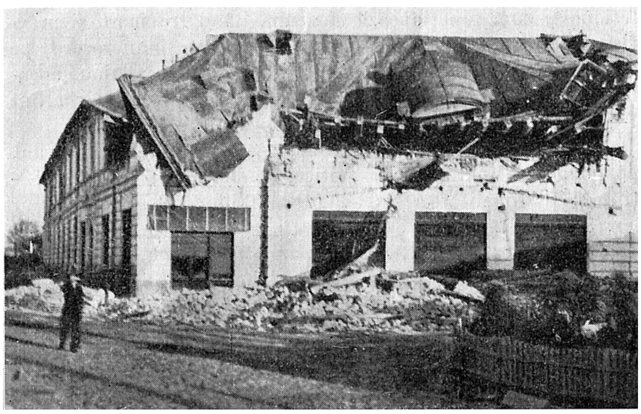


Figure 4. *Cont.*

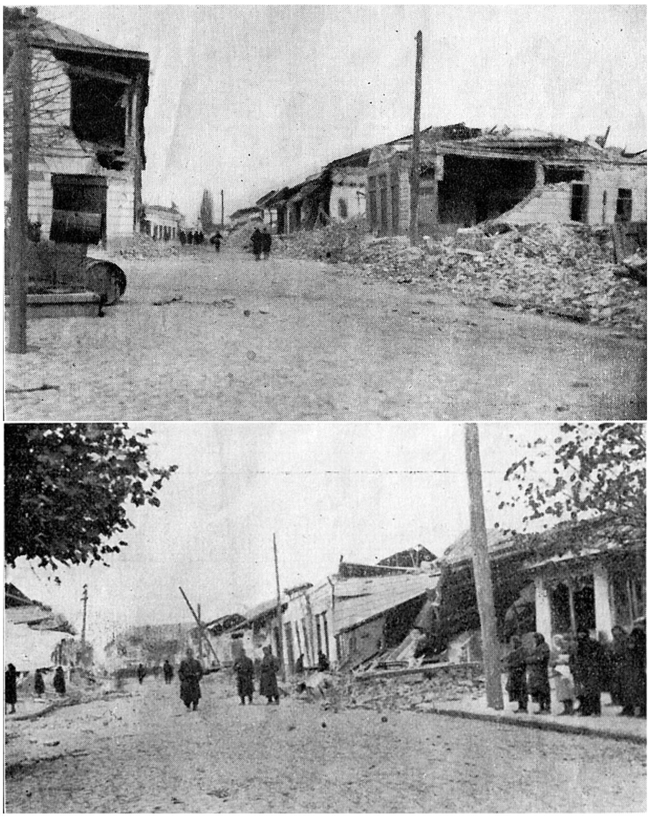


Figure 4. Typical damage of unreinforced masonry buildings in Panciu [21].

Figure 5 displays other failures of similar unreinforced masonry structures in other areas located near the epicentre of the earthquake (Focsani, Tecuci and Galati) [25,30].

(**a**)

Figure 5. *Cont*.

(**b**)

(**c**)

Figure 5. Typical damage of unreinforced masonry structures located in (**a**) Focsani [25], (**b**) Tecuci [25] and (**c**) Galati [30].

3. Comparison of the Effects of the Vrancea 1940 and 1977 Earthquakes

In this section, a comparison of the effects of the two largest Vrancea intermediate-depth earthquakes which occurred in the XXth century is shown. The comparison of the effects of the two events, which had different magnitudes and focal depths, might help in understanding the effects of future Vrancea large-magnitude earthquakes. The effects of the 1940 earthquake are assessed based on various sources in the literature, while in the case of the 1977 event, the effects are summarized in [31,32] as well as in other studies (e.g., [12,13]). The seismological characteristics of the 1977 Vrancea earthquake are discussed in a significant number of studies in the literature. According to the ROMPLUS earthquake catalogue (https://infp.ro/data/romplus.txt, accessed on 1 February 2024), the moment magnitude of the 1977 earthquake (M_W = 7.4) was smaller than that of the previous event in 1940, but the focal depth was significantly smaller (94 km vs. and estimated 150 km). Figure 6 shows the epicentre locations of the two events. It can be easily observed that the 1977 event was located much closer to Bucharest compared to the 1940 earthquake.

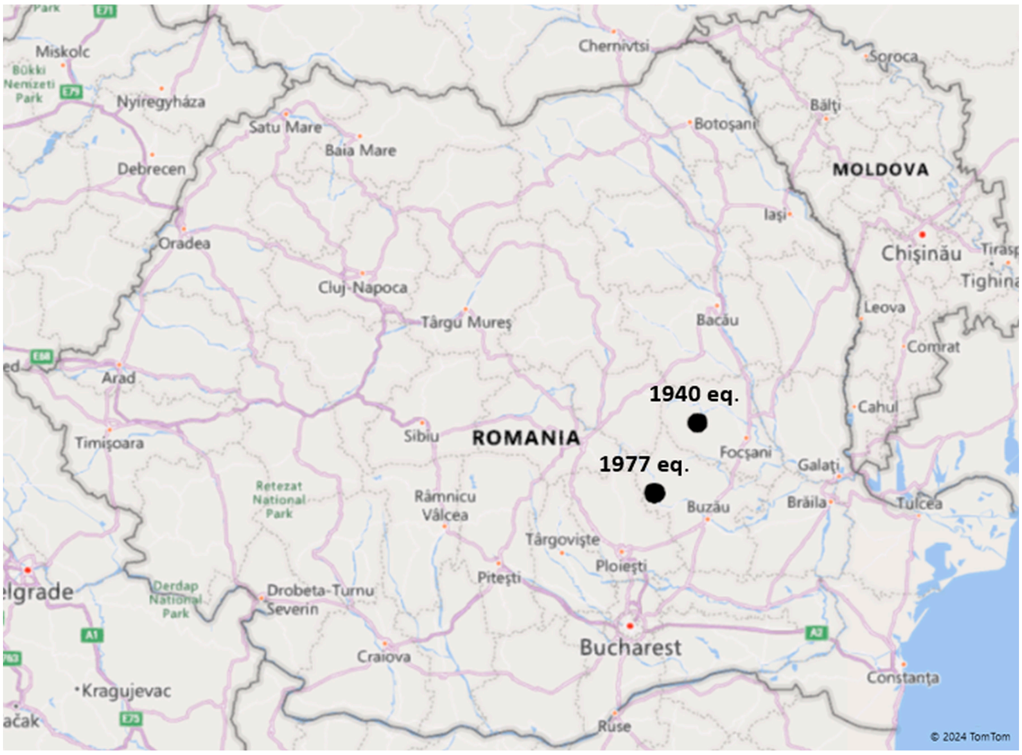


Figure 6. The epicentre locations of the two Vrancea intermediate-depth earthquakes in 1940 and 1977.

The main sources from which the effects of the 1940 earthquake can be evaluated are based on various journals from the time of the earthquake (e.g., Curentul and Universul), the transcripts of the meetings of the Romanian Government [33,34] from the same period, as well as from various journal papers. From the point view of the earthquake effects, the following sites were mentioned as being the most affected: Bucharest, Prahova, Barlad, Focsani and Galati.

The macroseismic intensities for 10 cities that were affected by the 1940 event are given in Table 1 using various references [22–24]. Significant differences between the macroseismic intensities can be observed for some sites (Braila, Buzau, Craiova and Iasi), as generally, the study of Kronrod et al. [22] (which is the most recent one) provides the largest levels.

A comparison of the number of buildings that were damaged or collapsed as a result of the two earthquakes is presented in Table 2. The numbers corresponding to the 1940 earthquake were reconstructed from various sources (mainly journal); thus, the uncertainty level is significantly larger than that in the case of the 1977 earthquake.

Table 1. A comparison of the macroseismic intensities of the cities affected by the Vrancea 1940 earthquake.

City	Macroseismic Intensity		
	Atanasiu and Kräutner [23]	Radulescu [24]	Kronrod et al. [22]
Barlad	IX	VIII–IX	VIII–IX
Braila	VII–VIII	VIII	VIII–IX
Buzau	VII	VIII–IX	IX
Craiova	VI–VII	VII	VII–VIII
Focsani	IX	IX	IX
Galati	VIII–IX	VIII–IX	IX
Iasi	VI–VII	VII–VIII	VII
Ploiesti	VII–VIII	VIII–IX	IX
Targoviste	VII–VIII	VIII	VIII
Tecuci	VIII	VIII–IX	IX

Table 2. A comparison of the number of damaged and collapsed buildings in Romania due to the Vrancea earthquakes in 1940 and 1977 [13].

Year of Earthquake	Collapsed Buildings	Damaged Buildings
1940	5900	43,500
1977	7270	58,677

3.1. Comparison of Territorial Damage Extent

In this section, a comparison of the effects of the two largest Vrancea earthquakes produced in the XXth century is presented. Based on the available literature, the comparison is performed in terms of the number of damaged buildings, the extent of damage and the casualties. A comparison of the territorial distribution of the effects of the major Vrancea earthquakes of 1940 and 1977 is shown in the study by Georgescu and Pomonis [35].

The first comparison involves the effects of the earthquakes in two counties, which are situated in the back-arc region of the Carpathian Arc, namely Sibiu and Brasov, and for which a significant ground motion attenuation of high frequency seismic waves occurs [36]. It can be observed from Table 3 that neither of the two earthquakes affected the Sibiu county. In the case of Brasov, fatalities were registered as a result of the 1977 earthquake.

Table 3. A comparison of the effects of the 1940 and 1977 Vrancea earthquakes in the Sibiu and Brasov counties.

County	1940 Earthquake			1977 Earthquake		
	Collapsed Buildings	Fatalities	Injuries	Collapsed Buildings	Fatalities	Injuries
Brasov	0	0	12	0	2	40
Sibiu	0	0	0	0	0	0

Another relevant comparison is made between the effects of the earthquake in two distant counties, namely Constanta and Dolj. The effects of the 1977 earthquake on the Constanta and Brasov counties are based on the reports of the Romanian State Security [37,38]. Relevant information about the effects of the 1977 earthquake in the Dolj county can be found in [39]. It can be observed from Table 4 that the effects of the 1977 earthquake were more important for both counties.

Table 4. A comparison of the effects of the 1940 and 1977 Vrancea earthquakes in the Constanta and Dolj counties.

County	1940 Earthquake			1977 Earthquake		
	Collapsed Buildings	**Fatalities**	**Injuries**	**Collapsed Buildings**	**Fatalities**	**Injuries**
Constanta	1	0	2	46	1	4
Dolj	<100	6	11	557	41	812

Finally, another comparison is made between the Prahova and Vrancea counties, situated near the Vrancea seismic source. It can be easily observed from Table 5 that the 1940 earthquake produced much more damage and many more fatalities and injuries in the Vrancea and Prahova counties compared to the subsequent 1977 event. The total losses in Vrancea county amounted to about 150 million lei the value at the moment of the earthquake). The losses in Tecuci, another significantly affected city, were estimated at roughly Romanian lei 55 million [33].

Table 5. A comparison of the effects of the 1940 and 1977 Vrancea earthquakes in the Prahova and Vrancea counties.

County	1940 Earthquake			1977 Earthquake		
	Collapsed Buildings	**Fatalities**	**Injuries**	**Collapsed Buildings**	**Fatalities**	**Injuries**
Prahova	700	63	196	<50	50	-
Vrancea	360	92	537	<50	2	23

3.2. A Comparison of the Effects in Bucharest

The effects of the two earthquakes on the building stock of Bucharest are quite difficult to evaluate. In both situations, the total number of damaged buildings can only be roughly estimated since the focus was on collapsed high-rise buildings, which caused the largest number of casualties (e.g., the Carlton building in the case of the 1940 earthquake). In addition, it has to be mentioned that, within the time frame between the two events, Bucharest doubled its population. Besides the Carlton building collapse, no other medium- or high-rise buildings collapsed in Bucharest. Significant damage was observed for low-rise masonry buildings located in the vicinity of the Dambovita river [19]. The execution, design and construction quality have been determined as causes of the collapse of the Carlton building [19,40,41] without any clear culprit.

Regarding the macroseismic intensity assigned for Bucharest for the two events, ref. [22] assigns a level of IX for the 1940 event and VIII for the 1977 earthquake. In this context, based on the data in Table 1, the macroseismic level IX assigned for the 1940 earthquake seems to clearly overestimate the real value for Bucharest. Moreover, the design macroseismic intensity according to STAS 2923-52 [42] for Bucharest in the 1952–1963 period was VIII, which was later reduced to VII for that period until 1977, when STAS 2923-63 [43] was applied.

A common observation made by various authors in a number of journals was that the buildings designed according to the Prescriptions of the German Commission for reinforced concrete from 1932, which were translated into the Romanian language [44], behaved in a very good manner during the earthquake. A critical issue which was mentioned in the above-mentioned prescriptions was related to the maximum allowable stress in the reinforced concrete of the columns, which is, of course, a measure of the sectional ductility as well. Another very important aspect mentioned in these Prescriptions was related to the necessity of designing the exterior columns to the combined action of the axial force and bending moment.

In this context, the considerable impact of the ground motion variability (which was not considered at the time of the event) is worth being mentioned as another reason for the different levels of damage in various locations within the city.

Among other effects of the 1940 earthquake in Bucharest, the following were retrieved from various sources:

- 46 damaged schools which could not be used after the event (out of 165);
- 4 damaged hospitals;
- 14 damaged churches;
- 3 damaged university buildings.

Various other observations related to the damage of buildings located in Bucharest can be found in the compiled literature. Some examples are given below:

- Torsional deformations were noticed in some buildings in Bucharest [40];
- More damage was observed in buildings with flexible (wooden) slabs [45];
- Pounding damage in buildings;
- Damage to masonry chimneys which were fixed at the base and unanchored at the top part [46].

Table 6 shows a comparison between the estimations for the number of collapsed and damaged buildings in Bucharest due to the 1940 and 1977 earthquakes. The figures for the 1977 event are very small, and the authors of [13] mentioned the tight political control in Bucharest and the building evacuation orders as possible reasons. Another report [47] assigned the total number of damaged buildings in Bucharest to about 35,000, a figure which represents an almost 20-fold increase from the estimate shown in Table 6.

Table 6. Comparison of the number of damaged and collapsed buildings in Bucaharest due to the Vrancea earthquakes in 1940 and 1977 [13].

Year of Earthquake	Collapsed Buildings	Damaged Buildings
1940	500	20,000
1977	157	2101

Another meaningful comparison of the two events involves the collapse and heavy damage rates of new medium- and high-rise buildings. The term new refers to buildings which were not affected at the time of the 1940 earthquake nor the 1977 earthquake. The rates are compared in Table 7. It is interesting to note in Table 7 that both rates are larger for the 1940 event. However, it has to be highlighted that the residential building stock of Bucharest was almost double at the time of the 1977 event.

Table 7. Comparison of the collapse and heavy damage rates for new buildings due to the Vrancea earthquakes in 1940 and 1977.

Year of Earthquake	Collapse Rate	Heavy Damage Rate
1940	0.12%	3.05%
1977	0.05%	2.86%

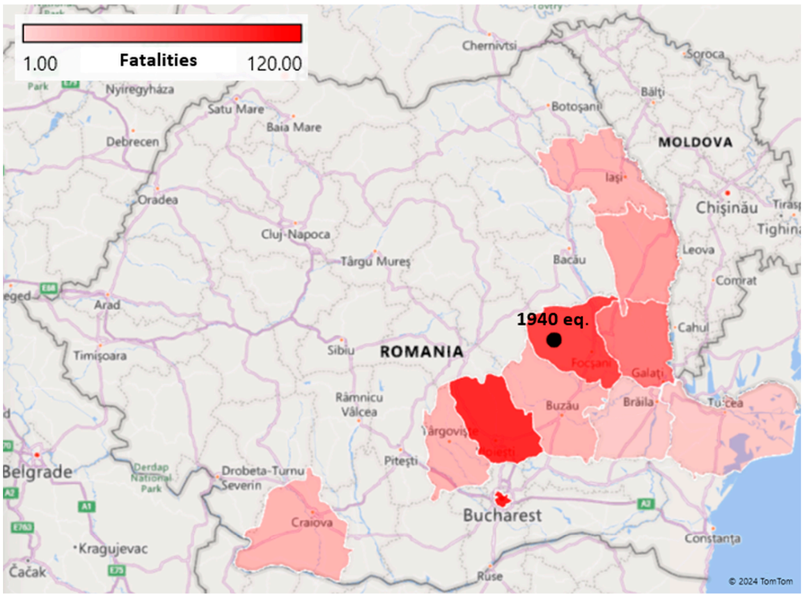
3.3. Comparison of Fatalities and Injuries

The number of fatalities occurring as a result of the two earthquakes is compared both in terms of numbers as well as in terms of causes. In the case of the 1977 event, the number of fatalities is clear [12]. The total number of fatalities and injuries in Romania as reported in [35] is shown in Table 8. One of the observations that can be made from the information shown in Table 8 is the very small ratio between the number of injuries and number of fatalities documented for the 1940 event (almost 3.5 times smaller than that of the 1977 earthquake). A different figure of 980 for fatalities, which is almost double the value shown in Table 8 for the 1940 earthquake, can be found in the EM-DAT database [48].

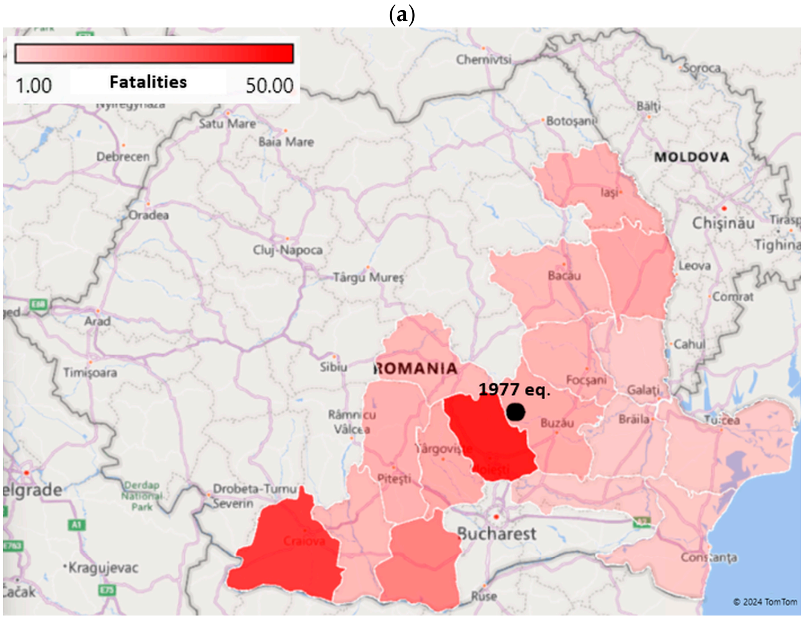
Table 8. Comparison of the number of fatalities and injuries in Romania due to the Vrancea earthquakes in 1940 and 1977 (Georgescu and Pomonis 2012).

Year of Earthquake	Fatalities	Injuries
1940	593	1271
1977	1578	11,321

Based on the available literature (mainly journal articles from Universul and Curentul), in this study, the estimated numbers of fatalities and injuries for the 1940 event are 423 and 1456, respectively. Figures 7 and 8 show a comparison performed at county level of the fatalities and injuries caused by the two seismic events. In total, fatalities and/or injuries during one or both the 1940 and 1977 earthquakes were identified in 19 counties. In the case of the injured people as a result of the 1977 earthquake, about 12% were unaccounted for in terms of their location. The representation for the 1977 event does not include Bucharest since 90% of the deaths and 70% of the injuries were located here.



(**a**)



(**b**)

Figure 7. Fatalities evaluated for the (**a**) Vrancea 1940 earthquake and (**b**) Vrancea 1977 earthquake.

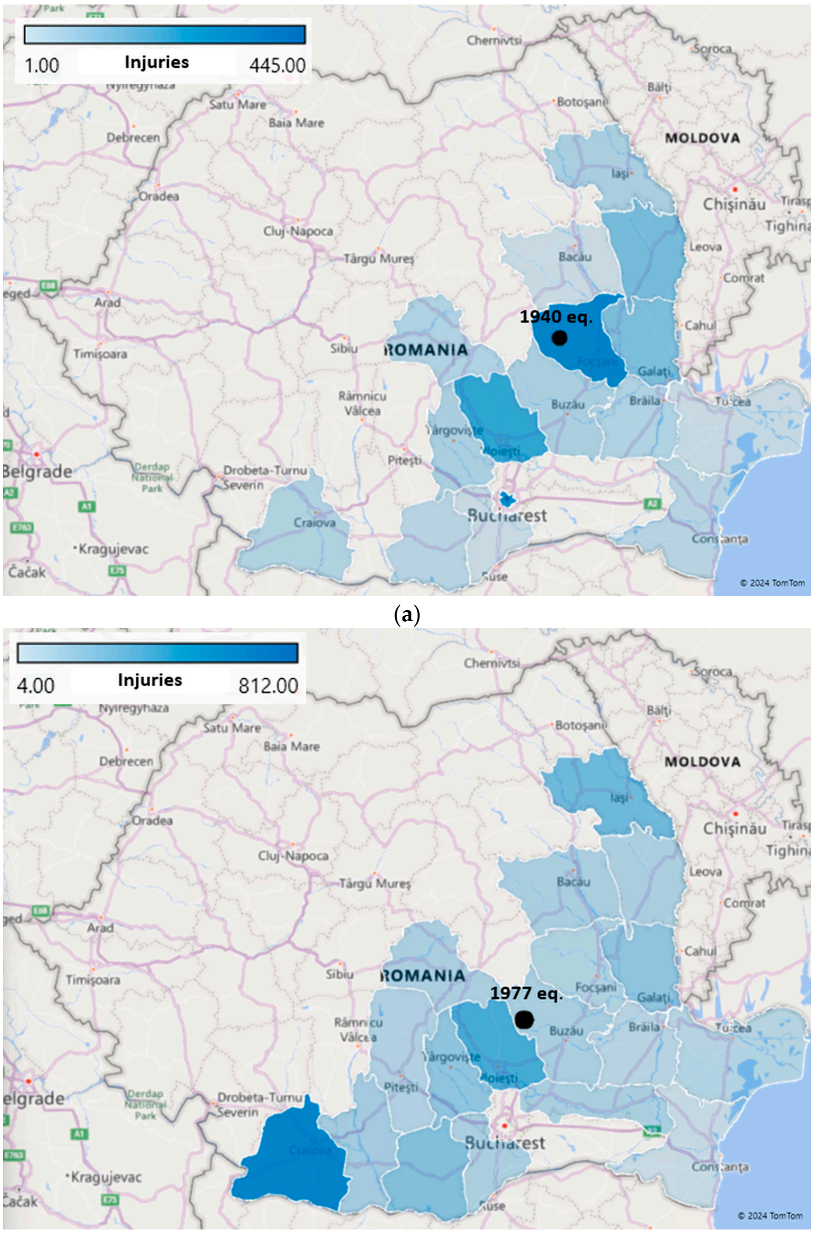


Figure 8. Injuries evaluated for the (**a**) Vrancea 1940 earthquake and (**b**)Vrancea 1977 earthquake.

A discussion regarding the fatalities during the Vrancea 1977 event is found in [49] and in [13]. Based on the two references, an estimation of the number of fatalities occurring due to the collapse of other structures, besides the total collapse of high-rise ones, can be performed. The resulting figure for the fatalities not linked with the total collapse of 23 high-rise buildings is 314. It has to be mentioned here that the fatalities due to the collapse of nine other high-rise buildings are also included in the total figure of 314. For the entire territory of Romania, since no other high-rise building collapsed, the total figure is 468. By estimating a fatality number of 150 due to the collapse of the remaining nine high-rise buildings in Bucharest, the final figure is 318. In the case of the 1940 event, by removing the fatalities due to the collapse of the Carlton building, the resulting figure is 304, which is very close to the one corresponding to the 1977 event. The lethality ratio of high-rise reinforced concrete structures is significantly larger than that proposed by Coburn and Spence [50], while in the case of masonry structures, it appears to be significantly smaller than that given in the same reference.

4. Assessment of Seismic Vulnerability of Pre-1940 Structural Typologies

The recently collected information regarding the effects of the 1940 Vrancea event allows for a tentative assessment of the seismic vulnerability of some structural typologies that were commonly used before 1940 for residential buildings. The assessment of the vulnerability of various pre-1940 structural typologies is performed using the macroseismic method in [51]. The macroseismic method has also been applied to evaluate the seismic vulnerability of various structural typologies in Bucharest in reference [52].

4.1. Medium- and High-Rise RC Residential Buildings in Bucharest

The category of buildings analysed in this subsection is the one which generated the largest number of fatalities as a result of the subsequent 1977 earthquake, when almost 30 such structures collapsed in Bucharest [32]. The first high-rise building with a reinforced concrete structure was constructed in the central part of Bucharest in the early 1930s, while the first block of flats was constructed 10 years before [53]. According to the figures given in [54], the earthquake resulted in the collapse of 1 high-rise building in Bucharest and heavy damage to an additional 25 medium- or high-rise buildings (some of these buildings collapsed due to the subsequent 1977 event).

The vulnerability parameters (V and Q) used in the macroseismic method of Lagomarisno and Giovinazzi [51] for this structural typology are estimated by minimizing the difference between the observed damage and the predicted damage. The main assumption of the computation is that all of the collapsed and heavily damaged buildings from the entire building stock were identified.

The mean damage degree for the entire dataset is 1.53 (assuming a macroseismic intensity level of VII–VIII), while the resulting values of the vulnerability parameters are V = 0.75 and Q = 2.30. A comparison of the binomial probability mass functions for the 1940 and 1977 earthquakes (assuming a macroseismic intensity level of VIII–IX) is shown in Figure 9 for the dataset of medium- and high-rise buildings constructed before 1940. It can be seen that the proportion of buildings with low or medium damage degrees is significantly larger in the case of the 1940 earthquake. The reasons for the larger damage degrees observed during the subsequent 1977 event can be the larger ground motion intensity in Bucharest coupled with the previous 1940 earthquake damage.

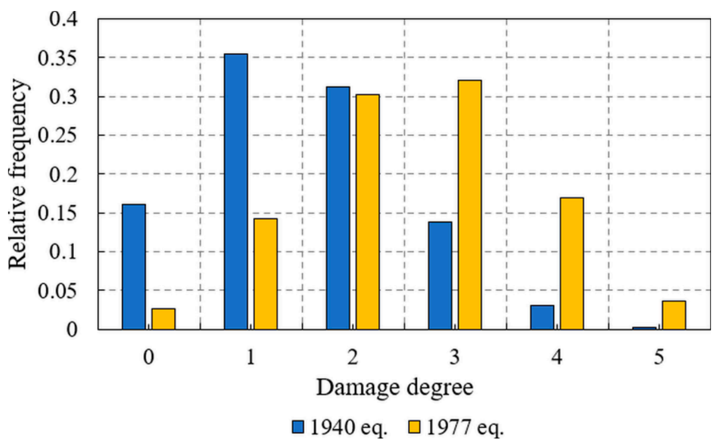


Figure 9. A comparison of the empirical damage probability histograms for medium- and high-rise RC buildings in Bucharest that were constructed before 1940 regarding the 1940 and 1977 Vrancea earthquakes.

4.2. Low-Rise Unreinforced Masonry Buildings in Barlad

The vulnerability characteristics of the unreinforced masonry buildings located in Barlad (one of the cities affected the most by the earthquake) are compared with the ones determined for similar buildings located in Bucharest after the Vrancea 1977 earthquake [55]. The vulnerability parameters (V and Q) used in the macroseismic method in [51] for the

Bucharest dataset were computed in the study by Lagomarsino and Giovinazzi [56] as 0.77 and 2.30, respectively.

The sample of masonry buildings with flexible floors for which the damage data are available consists of about 1200 buildings [57]. The data shown in the paper by Mandrescu [57] highlight a much larger percentage of damaged buildings that were observed for the structures with more than one storey in height. The mean damage degree for the entire dataset is 2.33 (assuming a macroseismic intensity level of VIII), while the resulting values of the vulnerability parameters are V = 0.79 and Q = 2.30, which are practically identical with the previous results obtained for Bucharest. This observation highlights the similarity in terms of the seismic vulnerability of unreinforced masonry structures constructed before 1940 irrespective of their location (Barlad or Bucharest). The empirical damage probability histograms for unreinforced masonry buildings located in Barlad for the 1940 earthquake are shown in Figure 10.

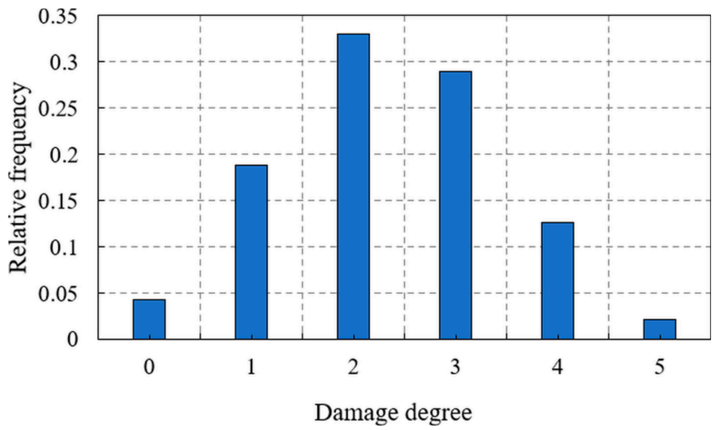


Figure 10. Empirical damage probability histograms for the unreinforced masonry structures in Barlad regarding the 1940 earthquake.

5. The Impact of the 1940 Earthquake on Building Designs and Construction Practices

Some remarks regarding the impact of the 1940 Vrancea earthquake on building designs can be found, for instance, in various studies (e.g., [58–60]). Starting from the above-mentioned references, newly collected information allows for a better and a more in-depth analysis of this issue. Recently, the evolution of seismic design codes and of the design codes for reinforced concrete (RC) structures in Romania has been analysed in the study by Pavel et al. [61]. All of the above-mentioned studies highlight the publication of the first official seismic design regulations in 1942 [62], which were later modified in 1945 [63] as a direct result of the 1940 earthquake. Even though until 1963, no other official seismic design code was enforced, the earthquake action was considered in the design of many buildings that were constructed in that period [61].

Until 1963, when the standard STAS 2923-63 [43] was issued, the seismic zonation only took into account the Vrancea intermediate-depth seismic source, with no other sources being considered. The design macroseismic intensities were based on the values observed as a result of the 1940 event [64].

Another important impact in terms of regulations is STAS 503-49 [65], which classifies loads into fundamental, accidental and extraordinary (with the seismic action being considered as extraordinary). For each permanent construction, extraordinary loads had to be considered. In some situations, a combination of an accidental load (e.g., wind and snow) with an extraordinary load (seismic action) was employed for design purposes.

An interesting consequence of the 1940 event is the use of braced reinforced concrete frames as structural systems for some residential buildings that were constructed in the aftermath of the event. Some examples of such structures still existing in Bucharest today are shown in Figure 11.

Figure 11. Examples of buildings with RC-braced frame structures that were constructed after the Vrancea 1940 earthquake.

Another noteworthy result of this earthquake was the issuing of a national design code for RC structures, which was published in 1942 [66] and was based on the 1932 Prescriptions of the German Commission for reinforced concrete.

Other important observations made from the 1940 earthquake which were introduced in construction practice were as follows [45,46,67]:

- The increase in the beam width, which, up to the moment of the earthquake, had widths of 14 cm;
- The introduction of ring beams along the masonry walls;
- A connection between the infill masonry panels and the vertical structural elements;
- The use of masonry or reinforced concrete lintels instead of wooden ones;
- The planar shape of buildings should be as regular as possible.

And a final and critical observation was that the structural layout should not depend on various architectural criteria [67] with more emphasis on the structure itself. This aspect led to an improved generation of residential buildings with a reinforced concrete frame structure being constructed in Bucharest until the introduction of the P13-63 code [68] and which performed well during the 1977 earthquake (better than some of the frames built in the 1970s). Some examples of such buildings are shown in Figure 12.

Figure 12. Examples of buildings with RC frame structures that were constructed after the Vrancea 1940 earthquake.

6. Repair, Strengthening Policy and Involvement of Authorities

A critical issue which has also consistently influenced the building damage observed as a result of the Vrancea 1977 earthquake was the policy for the repair and strengthening of the buildings after the 1940 event. In this context, some important aspects are given below:

- The majority of the partition walls with thicknesses of 7 or 14 cm were seriously damaged due to the earthquake. The common repairing approach applied after the earthquake, which did not involve injecting the cracks in the masonry walls, was noticed by some engineers, and a warning of possible collapses during future earthquakes was raised [67].
- No clear requirements regarding strengthening were available at the time.
- Some guidance on how to perform the repair of both the reinforced concrete and masonry structures was published after the event.
- The general view was that prescriptions for the strengthening of buildings were not necessary, as strengthening should be performed individually for each building based on its damage, its design and construction and the feasibility of such work [67].

Case studies in terms of repair and strengthening works for reinforced concrete structures were shown in an article written in 1945 by Prof. Hangan (one of the most famous engineers from that period) [69].

A more in-depth view of this issue can be obtained by analysing the documents written by architects and engineers after the event (sent by the Commission for Historical Monuments) who evaluated the states of various churches and monasteries and proposed various repair and strengthening strategies. Besides the repairing works that were carried out for the walls and ceilings which had cracks caused by the earthquake, two strengthening solutions are common to all of the affected monuments:

- The insertion of ties in order to connect the masonry walls;
- The insertion of ring beams made of steel profiles at the bottom part of the affected church towers, which were inserted in holes made in the masonry and covered afterwards (such that the steel elements were no longer visible).

From the point of view of the local authorities in Bucharest, the following measures were taken:

- All building owners were obliged to check and evaluate the damage states of their buildings (order issued in 24 November 1940);
- All architects and engineers had to check all of the buildings they designed in the past 10 years (order issued in 24 November 1940);
- Local authorities were entitled, based on a decision made by the Council of Ministers, to demolish buildings that suffered damage which jeopardized their stability and posed a threat to people’s safety;
- Commissions for evaluating the states of buildings were set up at the city district level, and another commission made up of some famous professors and engineers from that time was formed in order to check the damage states of high-rise buildings or buildings with complicated layouts;
- The role of evaluating buildings with more than 3–4 stories in height was only assigned to architects and engineers.

Consequently, based on the above-mentioned observations, it appears clear that from the point of view of damage evaluation, consistent measures were taken at the level of the local authorities from Bucharest. The second issue was that the repair and strengthening works and their quality were not regulated in any way (official requirements were only issued after 1990). In addition, no information about the use of temporary shelters (e.g., tents) for the affected people could be retrieved from the available information. It is important to note that tents may be a year-round solution for temporary shelters in mild climates [70], but in the case of the climate of Romania, heated tents are necessary during autumn or winter months.

According to the transcripts of the government meetings from May 1941 [34], the total loss for the education sector amounted to 1.32 billion lei, and only 200 million lei were allocated to various construction works. It has to be highlighted that the state budget for 1940 amounted to about 35 billion lei [71]; thus, the significant impact of the earthquake in terms of losses is visible.

Since no information regarding the impact on the residential building sector could be retrieved from the available sources, an estimation may be attempted based on the data collected after the 1977 earthquake [72], which basically show a 7-fold difference between the losses associated with residential buildings and the losses associated with buildings belonging to the cultural, educational or health domains. Consequently, the total losses due to this earthquake (including the indirect ones) definitely exceeded 50% of the total budget of Romania at the time of the event. Finally, it has to be highlighted that the budget of Romania in 1977 was about Romanian lei 280 billion, while the total earthquake losses are somewhere between 10 and 30% of that amount (depending on the conversion rate between the Romanian leu and US dollar), meaning that the 1940 event was significantly costlier than the 1977 one.

Other aspects related to the intervention of the state after the earthquake are given below:

- Long-term reconstruction loans with small interest rates were offered to those affected by the earthquake (it is not known if this measure was successful or not since Romania entered the Second World War 8 months after the earthquake);
- The maximum prices of construction materials were regulated [33];
- The owners or tenants whose buildings partially or totally collapsed due to the earthquake were indefinitely exempted from paying building taxes;
- Romanian lei 60 million was given by the Ministry of Finance for the repair of churches (the total losses amounted to about Romanian lei 800 million);
- An initial loan of Romanian lei 75 million, which was later extended to Romanian lei 320 million, was taken by the Romanian Government to repair construction projects that were affected by the earthquake [33];
- A rate of 0.017 Romanian lei/kg of oil was imposed in order to raise funds for the repair of public buildings in petroliferous counties.

Considering the onset of the Second World War in Romania, and due to the lack of financial means, it is clear that the Romanian Government was not able to spend more money on construction works for various public buildings. Thus, the majority of the works were simple repair works aimed at covering the effects of the earthquake.

7. The Impact of WW2 on the Building Stock of Romania

An important aspect which has not been mentioned previously and which may have influenced, to some extent, the seismic behaviour of the buildings in some major cities (e.g., Bucharest, Ploiesti, etc.) in Romania during the 1977 earthquake is related to the damage caused by the bombing campaign in the Second World War. In the case of Bucharest, the statistics of the damage caused by bombings in the 1941–1944 period [73] is as follows:

- 6111 fatalities, 6369 injured people and 43,585 homeless people;
- 7256 totally or partially destroyed buildings and 2909 damaged residential buildings;
- 154 totally or partially destroyed buildings and 113 damaged public buildings;
- 5450 totally or partially destroyed buildings and 1719 damaged commercial or industrial buildings.

It can be easily observed from the above-mentioned figures that the bombing campaign affected practically the same number of buildings as the 1940 earthquake, albeit the fatality rate was more than 40 times larger. Very little information is provided on how the repair or strengthening of buildings that were damaged due to the bombings took place and whether the affected people were helped by the state in any way.

8. Conclusions

This study presents a detailed perspective of the largest earthquake produced in the Vrancea intermediate-depth seismic source in the XXth century, namely the November 1940 earthquake. This earthquake was a shock for society at that time because no large-magnitude earthquake had occurred in Vrancea since 1838. Recently discovered studies in the literature from the time of the earthquake allowed for a more thorough evaluation of its effects and its impact on building designs and construction practices. Moreover, the repair and strengthening policy for buildings affected by the earthquake is also discussed based on relevant documents from the analysed period. Considering the objectives of this study mentioned in Section 1, the main observations and conclusions are given below:

- The seismic zonation of Romania until 1963 was based on the macroseismic intensities observed during the November 1940 earthquake.
- The publication of the first national code for the design and execution of concrete buildings in 1942, which was re-published in 1947, was a very important consequence of the earthquake.
- Specific construction requirements, which, today, are common knowledge (e.g., the introduction of ring beams along masonry walls, connections between the infill masonry panels and the vertical structural elements, regular shapes of the buildings in plane, etc.) were introduced in Romania as a result of the lessons learned from the 1940 earthquake.
- An improved generation of RC frame structures was built in the 1950s and had good seismic performance during the 1977 earthquake. In addition, RC-braced frames were also used as structural systems for residential buildings constructed after the earthquake.
- Significant differences between the macroseismic intensities evaluated in various studies can be observed for some sites (Braila, Buzau, Craiova and Iasi).
- The comparison of the effects of the 1940 and 1977 earthquakes revealed that there were more damage and more human casualties for the latter event in the case of more distant counties, while the former earthquake mainly affected the counties situated near its epicentre.
- A similar number of fatalities as a result of the collapse of non-high-rise buildings was observed for both the 1940 and 1977 earthquakes.
- In this study, the estimated numbers of fatalities and injuries for the Vrancea 1940 earthquake are 423 and 1456, respectively.
- The evaluated collapse and heavy damage rates for new medium- and high-rise buildings (at the time of the earthquake) are larger for the 1940 event.
- The vulnerability parameters for unreinforced masonry structures from Barlad were estimated as $V = 0.79$ and $Q = 2.30$, which are practically identical to the results obtained for Bucharest in a different study. This observation highlights the similarity in terms of the seismic vulnerability of unreinforced masonry structures that were constructed before 1940 irrespective of their location.
- From the point of view of damage evaluation, consistent measures were taken at the level of the local authorities from Bucharest. The main issue was that the repair and strengthening works and their quality were not regulated in any way (official requirements were only issued after 1990).
- The losses for the educational and religion sectors alone amounted to about Romanian lei 2.1 billion, which represents about 6% of the national budget for the year 1940. Thus, the total losses due to this earthquake (including the indirect ones) definitely exceeded 50% of the total budget of Romania, which means that this event produced more damage (as a proportion of the national GDP) than the 1977 event.
- The damage suffered by some buildings in the bombing campaign of the 1941–1944 period and the lack of adequate repair or strengthening works may have played roles in their poor seismic performance during the 1977 earthquake.

Finally, it is the author's point of view that the level of understanding of the 1940 earthquake effects and of the measures which had to be taken for both new and existing buildings by society itself and by the engineers and architects at that time was thorough. Unfortunately, the subsequent events which followed very soon after the earthquake influenced, in a dominant manner, the way in which all of the lessons learned from the earthquake were finally put into practice.

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References

1. Ismail-Zadeh, A.; Matenco, L.; Radulian, M.; Cloetingh, S.; Panza, G. Geodynamics and Intermediate-Depth Seismicity in Vrancea (the South-Eastern Carpathians): Current State-of-the Art. *Tectonophysics* **2012**, *530–531*, 50–79. [CrossRef]
2. Petrescu, L.; Borleanu, F.; Radulian, M.; Ismail-Zadeh, A.; Maţenco, L. Tectonic Regimes and Stress Patterns in the Vrancea Seismic Zone: Insights into Intermediate-Depth Earthquake Nests in Locked Collisional Settings. *Tectonophysics* **2020**, *799*, 228688. [CrossRef]
3. Gusev, A.; Radulian, M.; Rizescu, M.; Panza, G.F. Source Scaling of Intermediate-Depth Vrancea Earthquakes. *Geophys. J. Int.* **2002**, *151*, 879–889. [CrossRef]
4. Ambraseys, N.N.; Finkel, C.F. The Saros–Marmara Earthquake of 9 August 1912. *Earthq. Eng. Struct. Dyn.* **1987**, *15*, 189–211. [CrossRef]
5. Ambraseys, N. The Earthquake of 10 July 1894 in the Gulf of Izmit (Turkey) and Its Relation to the Earthquake of 17 August 1999. *J. Seismol.* **2001**, *5*, 117–128. [CrossRef]
6. Ambraseys, N.; Bilham, R. Reevaluated Intensities for the Great Assam Earthquake of 12 June 1897, Shillong, India. *Bull. Seismol. Soc. Am.* **2003**, *93*, 655–673. [CrossRef]
7. Tuttle, M.P.; Sykes, L.R. Re-Evaluation of Several Large Historic Earthquakes in the Vicinity of the Loma Prieta and Peninsular Segments of the San Andreas Fault, California. *Bull. Seismol. Soc. Am.* **1992**, *82*, 1802–1820.
8. Hough, S.E.; Armbruster, J.G.; Seeber, L.; Hough, J.F. On the Modified Mercalli Intensities and Magnitudes of the 1811–1812 New Madrid Earthquakes. *J. Geophys. Res. Solid Earth* **2000**, *105*, 23839–23864. [CrossRef]
9. Hough, S.E.; Hutton, K. Revisiting the 1872 Owens Valley, California, Earthquake. *Bull. Seismol. Soc. Am.* **2008**, *98*, 931–949. [CrossRef]
10. duPont, W.; Noy, I. What Happened to Kobe? A Reassessment of the Impact of the 1995 Earthquake in Japan. *Econ. Dev. Cult. Change* **2015**, *63*, 777–812. [CrossRef]
11. Sbeinati, M.R.; Darawcheh, R.; Mouty, M. The Historical Earthquakes of Syria: An Analysis of Large and Moderate Earthquakes from 1365 B.C. to 1900 A.D. *Ann. Geophys.* **2009**, *48*. [CrossRef]
12. Georgescu, E.-S.; Pomonis, A. 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. In Proceedings of the Proceedings of the 14th World Conference on Earthquake Engineering, Beijing, China, 12–17 October 2008.
13. Georgescu, E.-S.; Pomonis, A. New Archival Evidence on the 1977 Vrancea, Romania Earthquake and Its Impact on Disaster Management and Seismic Risk. In *Seismic Hazard and Risk Assessment*; Vacareanu, R., Ionescu, C., Eds.; Springer International Publishing: Cham, Switzerland, 2018; pp. 281–295.
14. Martin, S.S.; Li, L.; Okal, E.A.; Morin, J.; Tetteroo, A.E.G.; Switzer, A.D.; Sieh, K.E. Reassessment of the 1907 Sumatra "Tsunami Earthquake" Based on Macroseismic, Seismological, and Tsunami Observations, and Modeling. *Pure Appl. Geophys.* **2019**, *176*, 2831–2868. [CrossRef]
15. Hough, S.E. Missing Great Earthquakes. *J. Geophys. Res. Solid. Earth* **2013**, *118*, 1098–1108. [CrossRef]
16. Buforn, E.; López-Sánchez, C.; Lozano, L.; Martínez-Solares, J.M.; Cesca, S.; Oliveira, C.S.; Udías, A. Re-Evaluation of Seismic Intensities and Relocation of 1969 Saint Vincent Cape Seismic Sequence: A Comparison with the 1755 Lisbon Earthquake. *Pure Appl. Geophys.* **2020**, *177*, 1781–1800. [CrossRef]
17. Pavel, F.; Vacareanu, R. Assessment of the Ground Motion Levels for the Vrancea (Romania) November 1940 Earthquake. *Nat. Hazards* **2015**, *78*, 1469–1480. [CrossRef]
18. Pavel, F.; Vacareanu, R. Re-Assessment of Peak Ground Accelerations for Large Magnitude Vrancea Intermediate-Depth Earthquakes. *J. Seism.* **2020**, *24*, 1271–1280. [CrossRef]
19. Beleș, A. Le Tremblement de Terre Du 10 Novembre 1940 et Les Batiments. *Comptes Rendus Sceances L'academie Sci. Roum.* **1941**, *5*, 270–287.

20. Georgescu, E.-S. The Collapse of Carlton Building in Bucharest at November 10, 1940 Earthquake: An Analysis Based on Recovered Images. In *1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt*; Vacareanu, R., Ionescu, C., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 57–72.
21. Capatana, A. *The History of Panciu and the Brazi and Saint John Hermitages*; Tiparul Cartea Romaneasca: Bucharest, Romania, 1941.
22. Kronrod, T.; Radulian, M.; Panza, G.; Popa, M.; Paskaleva, I.; Radovanovich, S.; Gribovszki, K.; Sandu, I.; Pekevski, L. Integrated Transnational Macroseismic Data Set for the Strongest Earthquakes of Vrancea (Romania). *Tectonophysics* **2013**, *590*, 1–23. [CrossRef]
23. Atanasiu, I.; Kräutner, T. Das Erdbeben Vom 10 November 1940 in Rumänien. *Veröffentlichungen Reichsanst. Prdbebentorschung Jena* **1941**, *40*, 7–30.
24. Radulescu, N. Considerations Geographiques Sur Le Tremblement de Terre Du 10 Novembre 1940. *Comptes Rendus Sceances L'academie Sci. Roum.* **1941**, *5*, 243–269.
25. Radulescu, N. *Research on the November 10, 1940 Earthquake in the South Part of Moldova*; Tipografia Ziarului Universul: Bucharest, Romania, 1941.
26. Hariri-Ardebili, M.A.; Tosun, H. Dams in the Wake-up Call of the 2023 Türkiye Earthquake Sequence: Insights from Observed Damages, Risk Assessment, and Monitoring. *Int. J. Disaster Risk Reduct.* **2024**, *102*, 104284. [CrossRef]
27. Prager, E. *Reinforced Concrete in Romania*; Ed. Tehnica: Bucharest, Romania, 1979; Volume 1.
28. Lozincă, E.; Seki, M.; Văcăreanu, R.; Okada, T.; Georgescu, B.; Kaminosono, T.; Kato, H. Seismic Rehabilitation of an Existing Pre-1940 Building. Case-Study. In *International Symposium on Seismic Risk Reduction*; Orizonturi Universitare: Bucharest, Romania, 2007; pp. 207–220.
29. Miron, R. A Human Tragedy in Putna County: The November 10, 1940 Earthquake. *Cron. Vranc.* **2011**, *10*, 193–235.
30. Kräutner, T. Buildings Collapsed in Galati Due to the Earthquake. *Natura* **1941**, *30*, 1.
31. ICCPDC. *The March 4, 1977 Earthquake in Romania and Its Effects on Constructions*; Bucharest, Romania, 1978; Volume 1.
32. Balan, S.; Cristescu, V.; Cornea, I. *The March 4, 1977 Romanian Earthquake*; Academiei: Bucharest, Romania, 1982.
33. *National Archives of Romania Transcripts of the Meetings of the Council of Ministers—September–December 1940*; Bucharest, Romania, 1997; Volume 1.
34. *National Archives of Romania Transcripts of the Meetings of the Council of Ministers—April–June 1941*; Bucharest, Romania, 1997; Volume 3.
35. Georgescu, E.S.; Pomonis, A. Building Damage vs. Teritorial Casulaty Patterns during the Vrancea (Romania) Earthquakes of 1940 and 1977. In Proceedings of the 15th World Conference on Earthquake Engineering, Lisbon, Portugal, 24–28 September 2012.
36. Pavel, F.; Vacareanu, R. Investigation on Regional Attenuation of Vrancea (Romania) Intermediate-Depth Earthquakes. *Earthq. Eng. Eng. Vib.* **2018**, *17*, 501–509. [CrossRef]
37. CNSAS. The March 4, 1977 Earthquake in the Documents of the Brasov Security Service. Available online: http://www.cnsas.ro/documente/judete/Brasov/14.pdf (accessed on 16 April 2024).
38. CNSAS. The March 4, 1977 Earthquake. *Reports and Syntheses of the Security Service.* Available online: http://www.cnsas.ro/documente/judete/Constanta/6 (accessed on 16 April 2024).
39. Trita, L.; Gavrila, V.; Babalau, N. *The Longest Night of Craiova*; Scrisul Romanesc: Craiova, Romania, 1978.
40. Sfintescu, C. Seismic resistance of buildings. *Urbanismul* **1940**, *17*, 266–269.
41. Achim, T. *The Causes of the Collapse of the Carlton Building. Lessons Learnt*; Tiparul Cartea Românească: București, Romania, 1941.
42. Standardization Commission. *STAS 2923-52 Construction Loads. Macroseismic Intensity Zones*; Standardization Comission: Bucharest, Romania, 1952.
43. *OSS STAS 2923-63*; Construction Loads. Macroseismic Intensity Zones: Bucharest, Romania, 1963.
44. Hangan, M. *Presciptions of the German Commission for Reinforced Concrete 1932*; Institutul de Arte Grafice: Bucharest, Romania, 1932.
45. Enescu, I.D. Architecture and earthquake. *Arhitectura* **1940**, 6–7.
46. Sfintescu, C. Urban planning and constructions in Romania with reference to seismic ground motions. *Urbanismul* **1940**, *17*, 215–220.
47. IPB. *Study Regarding the Effects of the March 4, 1977 Earthquake on the Old and New Residential and Social-Cultural Buildings in the Specific Conditions of Bucharest*; IPB: Bucharest, Romania, 1978.
48. Centre for Research on the Epidemiology of Disasters EM-DAT | The International Disasters Database. Available online: https://public.emdat.be/data (accessed on 16 December 2023).
49. Steinbrueck, K. Aftershocks: Nicolae Ceauşescu and the Romanian Communist Regime's Responses to the 1977 Earthquake. Ph.D. Thesis, Northwestern University, Evanston, IL, USA, 2017.
50. Coburn, A.; Spence, R. *Earthquake Protection*, 2nd ed.; Wiley: Hoboken, NJ, USA, 2002; ISBN 978-0-470-84923-1.
51. Lagomarsino, S.; Giovinazzi, S. Macroseismic and Mechanical Models for the Vulnerability and Damage Assessment of Current Buildings. *Bull. Earthq. Eng.* **2006**, *4*, 415–443. [CrossRef]
52. Pavel, F.; Vacareanu, R. Scenario-Based Earthquake Risk Assessment for Bucharest, Romania. *Int. J. Disaster Risk Reduct.* **2016**, *20*, 138–144. [CrossRef]
53. Enescu, I.D. Dwelling aspects in Romania. In *Dwelling in Romania*; Institutul Urbanistic al Romaniei: Bucharest, Romania, 1932; pp. 27–45.
54. Ignat, G. Can We Build High-Rise Buildings in Bucharest? *Municipal Gazette* **1940**, 3.

55. Sandi, H. WG Vulnerability and Risk Analysis for Individual Structures and Systems. In *Report to the 8th European Conference on Earthquake Engineering*; EAEE: Lisbon, Portugal, 1986.
56. Pavel, F.; Calotescu, I.; Vacareanu, R.; Sandulescu, A.-M. Assessment of Seismic Risk Scenarios for Bucharest, Romania. *Nat. Hazards* **2018**, *93*, 25–37. [CrossRef]
57. Mandrescu, N. On the seismic microzonation of the city of Barlad. *Stud. Si Cercet. Geol. Geofiz. Si Geogr.* **1966**, *4*, 237–244.
58. Calotescu, I.; Neagu, C.; Lungu, D. Before and After November 10th, 1940 Earthquake. In *1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt*; Vacareanu, R., Ionescu, C., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 37–55.
59. Petrovici, R. The 10 November 1940—The First Moment of Truth for Modern Constructions in Romania. In *1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt*; Vacareanu, R., Ionescu, C., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 85–99.
60. Vlad, I. Causes and Effects of the November 10, 1940 Earthquake. In *1940 Vrancea Earthquake. Issues, Insights and Lessons Learnt*; Vacareanu, R., Ionescu, C., Eds.; Springer International Publishing: Cham, Switzerland, 2016; pp. 113–128.
61. Pavel, F.; Crowley, H.; Romão, X.; Vladut, R.; Pereira, N.; Ozsarac, V. Evolution of National Codes for the Design of RC Structures in Romania. *Bull. Earthq. Eng.* **2023**, *22*, 911–949. [CrossRef]
62. MLPC. *Provisional Instructions for the Prevention of Construction Damage Due to Earthquakes and for the Repair of Damaged Ones*; MCLP: Bucharest, Romania, 1942.
63. MCLP. *Instructions for the Prevention of Construction Damage Due to Earthquakes*; MCLP: Bucharest, Romania, 1945.
64. Siara, V. Aspects regarding the macrozonation of the territory of Romania from STAS 2923-63. *Standardizarea* **1964**, *16*, 16–20.
65. *OSS STAS 503-49*; Loads in Constructions. Classification. OSS: Bucharest, Romania, 1949.
66. MLPC. *Prescriptions for the Design and Execution of Reinforced Concrete Constructions*; MLPC: Bucharest, Romania, 1942.
67. Ioanovici, A. The problem of general prescriptions for the strenghtening of buildings affected by the earthquake. *Bul. AGIR* **1941**, *22*, 14–16.
68. *CSCAS P13-63*; Code for the Design of Civil and Industrial Buildings in Seismic Regions. CSCAS: Bucharest, Romania, 1963.
69. Hangan, M. Strengthening of foundations and reinforced concrete constructions. *Bull. Soc. Politeh. Din. Rom.* **1945**, *59*, 112–160.
70. Moustafa, K. Tent-Cities: A Resilient Future Urban Solution to Live and Mitigate Earthquake Damages. *Cities* **2024**, *145*, 104696. [CrossRef]
71. General Statistical Institute. *Statistical Yearbook of Romania for 1939 and 1940*; IGS: Bucharest, Romania, 1940.
72. *The World Bank Report and Recommendation of the President of the International Bank for Reconstruction and Development to the Executive Directors on a Proposed Load to the Investment Bank with the Guarantee of the Socialist Republic of Romania for a Post Earthquake Construction Assistance Project*; The World Bank: Washington, DC, USA, 1978.
73. Arma, A. *Bucharest under Bombs 1941–1944*; Militară: Bucharest, Romania, 2020.