Seismic Vulnerability Scenarios for Timisoara, Romania

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Abstract. Romania is an European country with two major seismic zones, Vrancea and Banat. Timisoara is one of the biggest cities in Romania, located in Banat seismic area, characterized by shallow earthquakes, with depths between 2 and 20 km and important vertical forces. In the historical area of Timisoara there were classified different types of structures, using the HAZUS method (HAZUS 1999).

Seismic vulnerability analysis was done using different methodologies, Vulnerability Index, Tremuri, Vulnus and the Romanian methodology according to code P100-3/2013 in order to assess the behavior of historical buildings. Based on the results obtained after applying the three methodologies, there will be further made fragility curves for buildings located in the 3 historic zones of Timisoara city. In particular the probability to have in-plane or out-of-plane damages obtained by Vulnus is correlated with the results of the nonlinear analysis made with Tremuri software considering different limit state. Subsequently, considering the typical earthquakes in Banat area, it was possible to define the seismic response for three buildings, as a preview of seismic response of the city and the impact of the earthquake. This type of analysis was made for the most frequent earthquake type. This article makes plain the first step in estimating the hazard seismic scenarios for the evaluation of the losses in terms of human life and financial problems, offering the support for further prevention and intervention strategies.

Keywords: Earthquake · Vulnerability · Prevention · Probability Strategy

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1 Seismicity of Romania

Romania is a country with almost 20 million citizens, located in the Eastern Europe, with a very complex landscape, including the Danube River, the Carpathian Mountains and the Black Sea shore. The country is characterized by two major seismic zones, very different from each other [1].

The first and the most important one is Vrancea seismic zone, which affects the SE part of the country and is located on the Moesian Platform, over three tectonic units in contact [2]. This type of crustal block generates intermediate-depth earthquakes (60–200 km) with stress regime predominantly compressive at depth and magnitude over 7 Mw [1].The second seismic zone in Romania is Banat area [3], as we can see in Fig. 1, located in the western part of Romania, at the contact between the Pannonia Depression and the Carpathian Mountains. It is characterized by small depth events, high activity, with magnitude that does not exceed 5.6 Mw, presenting very strong vertical forces [4].

Fig. 1. Seismicity of Romania

For a returning period of 475 years, the magnitude for Banat seismic zone is estimated 6.3 on Richter scale and the intensity is considered VIII-IX on Mercalli scale [5]. In the actual seismic design code for Romania, the Peak Ground Acceleration is considered 0.20 g for Timisoara.

2 The Case Study Site

2.1 Timisoara City

Timisoara is the 3rd biggest city in Romania, with more than 300000 inhabitants, developed along Bega River, first mentioned as a place in year 1212. During the Ottoman administration (1552), Timisoara developed a very strong defense system, based on massive masonry fortress walls that had been protecting the city for many years. Starting with year 1716, with the Habsburgic administration, the city started to develop on the outside part of the defense walls, creating the residential zones Iosefin and Fabric. All the new areas kept initially a 948 m distance from the defense walls, because of strategic reasons [3], but later all the zones merged together. Nowadays, the city has three major historic zones, named Cetate (inside the defense walls), Iosefin and Traian, that can be correlated through a cultural promenade, as we can see in Fig. 1b [6]. Recently, Timisoara was elected to be European Capital of Culture for 2021, so the study of vulnerability of main historic buildings is imperative in order to assure the safety of citizens and visitors.

2.2 Fabric Zone

Fabric zone is located in the western part of Timisoara city, first mentioned in year 1720, developed at first as a zone for the workers of the city, characterized by small simple houses. Only in the 19^{th} century the area developed into a multifunctional zone, with residential spaces, commercial and public buildings. The small old buildings get united into a common street line and there seem to start appearing bigger and taller constructions, in Neoclassic, Eclectic and Secession style. At the end of the 19^{th} century, almost 50% of the population of the city lived in Fabric [7]. That is why the presented study was made in precisely this area, because there are some historical buildings that are very important to the community memories.

3 Seismic Vulnerability of Selected Buildings

3.1 Short Description of the Buildings

The first study was made on 11 buildings from Fabric historic area, and there were identified, according to HAZUS methodology, two different types of buildings such as URM (unreinforced masonry buildings, 10 buildings) and RM (reinforced masonry with metallic ties in the structural walls, one building) [8]. For further investigation, the first category called URM buildings was chosen. There were also noticed three repetitive typologies (Type I, II and III), which derive from the main category, based on the number of levels. This categories can further be divided in another two subcategories based on type of the floors and another two based on the existence of a weaken ground floor (Table 1). From the 10 investigated buildings, the number of the buildings from each category is shown in Table 2 and the structural typology is illustrated in Fig. 2.

One of those typologies to be further analyzed is the most common one, type III.1, having big masses, biggest height (basement + ground floor + 2 floors), masonry structure, masonry vaults over basement and wooden floors over ground, first and second floor. From the ten investigated buildings, five of them are part of this specific typology. From this five buildings, one of them present weak ground floor due to functional modifications and four of them are without weak ground floor. From those buildings with similar characteristics, there were chosen three to be further investigated, all three type III.1.2. The selected buildings, dating from 19^{th} century, are showed in Fig. 3a and b. Two of them have a corner position and the other one has an end position into the aggregate. The physical state of the buildings is generally a good

Table 1. Typologies of buildings from URM category

Type of floors		Masonry vaults above basement + wooden floors above all other floors (Type 1)		Masonry vaults above basement + ceramic elements above ground floor + wooden floors above all other floors (Type 2)	
Weak ground floor		Yes	No	Yes	No
No. of levels above basement	1 (Type I)	I.1.1	I.1.2	I.2.1	I.2.2
	2 (Type II)	II.1.1	II.1.2	II.2.1	II.2.2
	3 (Type III)	III.1.1	III.1.2	III.2.1	III.2.2

Table 2. Number of buildings according to the identified typologies

Type I				Type II				Type III			
1		2		1		2		1		2	
1	2	1	2	1	2	1	2	1	2	1	2
–	II	–	–	–	II	–	–	II	III	I	–

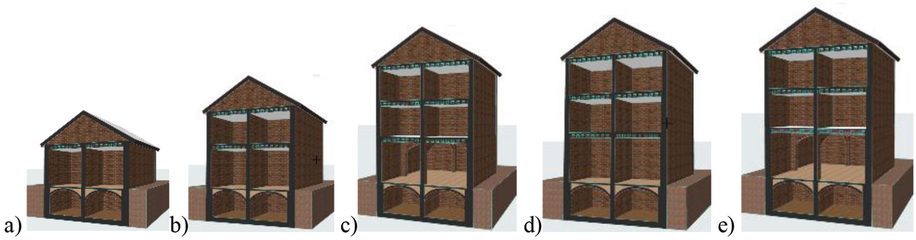

Fig. 2. The structural typologies identified between the ten studied buildings from Fabric zone: (a) Type I.1.2; (b) Type II.1.2; (c) Type III.1.1; (d) Type III.1.2; (e) Type III.2.1.

one, without visible structural cracks. Main problems are caused by the lack of proper intervention and exposure to climate changes, as we can see in Fig. 4a–c.

First building is located on 11, August 3rd Street (Bld.1), with an ending position into the aggregate and a rectangular shape. The area is about 450 m^2 and the height is over 14 m. The second building is called Princesses Mirbach Palace (Bld.2) and it is located in Traian square, the most important place of Fabric area, in a corner position into the aggregate and an L-shape. The height is 20 m and the area about 1000 m^2. The third building is called Karl Kunz Palace (Bld.3) and it is located on 3, August 3rd Street, in a corner position into the aggregate. It has an L-shape, an area about 600 m^2 and a height of 14 m. For all three buildings, the structure is made in masonry walls, with masonry vaults over basement and wooden floors above the other levels.

Fig. 3. (a) Possible cultural promenade; (b) The selected buildings from Fabric zone

Fig. 4. The selected buildings; (a) 3 August no. 11 Palace; (b) Princesses Mirbach Palace; (c) Karl Kunz Palace.

3.2 Seismic Vulnerability Index by Empirical Method

The first methodology that was applied is called Vulnerability Index Method (VIM). The first methodology considered 10 parameters and was put forward by Benedetti and Petrini [9]. Later, the methodology was developed to 15 parameters by the University of Naples [10]. This method is based on parameters that are considered relevant based on more than 25 years of experience on studying the effects of earthquakes, taking into consideration the geometrical and structural characteristics of the building and also the influence of the adjacent buildings [11]. The first ten parameters taken into account, are related to organization and nature of vertical structure, location of the building and type of foundation, in-plane and vertical regularity, type of floor, roofing, physical condition and other details. The other five parameters consider position of the building into the aggregate, presence of adjacent buildings with different heights, number of staggered floors, heterogeneity among structural units and opening areas. The overall vulnerability represents the sum of 15 parameters, each of them having assigned weight factor, related to four classes of increasing vulnerability [12]. After studying the three buildings from Fabric zone, the vulnerability indexes obtained for both 10 (I_V10) and 15 (I_V15) parameters are illustrated in Table 3.

Table 3. Vulnerability indexes for the three studied buildings with vulnerability index method

Building	3 August nr.11 (Bld. 1)		Princesses Mirbach Palace (Bld. 2)		Karl Kunz Palace (Bld. 3)	
	I_V 10	I_V 15	I_V 10	I_V 15	I_V 10	I_V 15
$I_{v\ VIM}$	0.39	0.39	0.21	0.40	0.30	0.24

By applying the formula described in Eq. (1), were the intensity is considered I = 8 and ϕ = 2.3 (specific for residential building) and taking into consideration Table 4 [13], for the first, second and third building the mean damage indexes were obtained. As we can see in Table 5 the most probable damage states are D1 (slight damage) for all the three buildings.

$$\mu_D = 2.5\left[1 + \tanh\left(\frac{I + 6.25I_{V10} - 13.1}{\phi}\right)\right] \tag{1}$$

Table 4. Correlation between mean damage index intervals and mean probable damage state

Mean damage index intervals (μ_D)	Most probable damage state	Most probable level of damages
0.0–1.5	D1	Slight
1.5–2.5	D2	Moderate
2.5–3.5	D3	Substantial to heavy
3.5–4.5	D4	Very heavy
4.5–5.0	D5	Destruction

Table 5. Mean damage indexes and damage states with vulnerability index method

Building	3 August nr.11 (Bld. 1)		Princesses Mirbach Palace (Bld. 2)		Karl Kunz Palace (Bld. 3)	
	μ_D	Damage state	μ_D	Damage state	μ_D	Damage state
	0.45	D1	0.18	D1	0.28	D1

3.3 Seismic Vulnerability Index by Mechanical Method

The nonlinear models are effective tools for the assessment of existing masonry buildings. Tremuri software allows us to obtain the nonlinear seismic analyses [14]. According to the Romanian legislation [15], the performance point was determined based on the acceleration spectrum. After analyzing the three buildings from Fabric zone, as we can see in Fig. 5 there were obtained the pushover curves [16] and the performance points. Based on the report between capacity and demand, there were obtained the mechanical vulnerability indexes and the most probable damage state for the three studied buildings, using Eq. 1, as we can see in Table 6.

Vulnus software tells us the probability that one building exceeds its structural capacity, both for in-plane and out-of-plane failure mechanism [17]. The results showed that there is more likely to be activated the in-plane failure mechanisms for all three buildings, and the evaluation of the vulnerability for all buildings is very low, as we can see in Table 7.

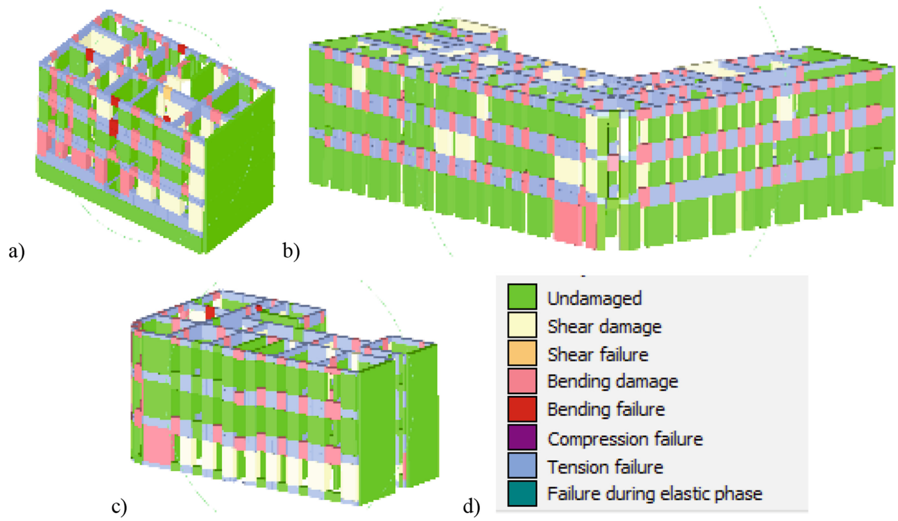

Fig. 5. Tremuri analysis results; (a) 3 August no. 11 Palace (Bld.1); (b) Princesses Mirbach Palace (Bld.2); (c) Karl Kunz Palace (Bld.3); (d) legend of colours.

Table 6. Vulnerability indexes for the three studied buildings with mechanical method

Building	3 August nr.11 (Bld. 1)	Princesses Mirbach Palace (Bld. 2)	Karl Kunz Palace (Bld. 3)
$I_{v\ mec}$	0.33	0.28	0.29
Most probable damage state	D1	D1	D1

Table 7. Vulnerability with Vulnus: (a) for 3 August no.11 Palace; (b) for Princesses Mirbach Palace; (c) for Karl Kunz Palace;

Building	3 August no.11 (Bld. 1)	Princesses Mirbach Palace (Bld. 2)	Karl Kunz Palace (Bld. 3)
Vulnerability	Very low	Very low	Very low

3.4 Comparison Between Seismic Vulnerability Methodologies Results

The seismic vulnerability classes after Romanian Code P100-3/2013 for existing buildings is obtainedbased on R_3 index, obtained with Eq. 2, where $d_s$is the displacement by seismic design for the ultimate limit state (demand) and d_u is the ultimate displacement of the building (capacity) [15].

$$R_3 = \frac{d_u}{d_s} \tag{2}$$

Overall, when comparing all the results (nonlinear analysis based on Tremuri software and Romanian code P100-3/2013, Vulnerability Index Method and Vulnus) we can see that the results are correlated. For the Italian methodologies, the vulnerability class is not changed (low vulnerability for all three buildings and slight damages), as we can see in Fig. 6a. According to the Romanian Code P100-3/2013, the vulnerability class of all three buildings is R_SIII, which means moderate to low vulnerability. The results are displayed below (Fig. 6b), meaning possibility of having also structural damages, which shows the fact that the Romanian vulnerability methodology is one level more restrictive. For intensities varying from 5 to 12, the vulnerability curves are shown in Fig. 7.

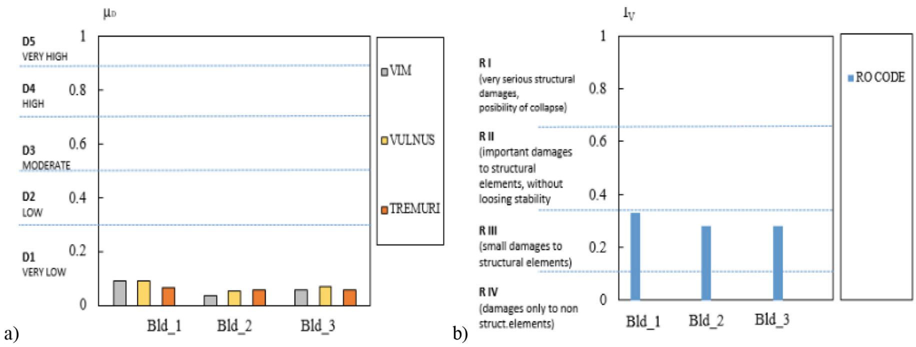

Fig. 6. Comparison between most probable damage classes; (a) the Italian methodologies; (b) Romanian code P100-3/2013

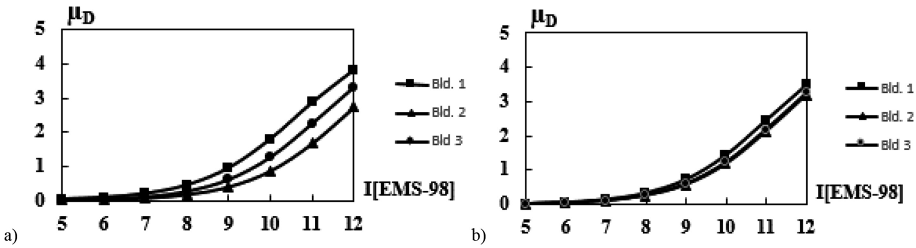

Fig. 7. Vulnerability curves for: (a) Vulnerability Index methodology; (b) Mechanical methodology

4 Conclusions

The results illustrate a very good correlation between the Italian seismic vulnerability methodologies. The level of low vulnerability indicated by the Italian methodologies is in harmony with the lack of structural damages that were found during inspection on site. Is necessary to point to the fact that the Romanian code is too conservative and difficult for a designer to work by relying on it without a significant amount of information from inside of a building. Starting from this fact, the fragility curves must be improved for the shallow earthquakes, which are specific to Banat seismic area, to allow us predict the seismic impact at urban scale.

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