Assessing seismic vulnerability for historical buildings in Timisoara – Romania and relating it on multiple domains such as: population, economy, infrastructure

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ABSTRACT

Timisoara is one of the biggest cities in Romania, located in the Banat plain. The area in which the city is located is the second most hazardous seismic zone in the country – Banat region, which is subjected to shallow earthquakes, the main particularities of this type being the small depth of the seismic source and a reduce surface of the epicenter area.

The main objective of this paper is based on both the evaluation of the seismic vulnerability analyzed in one of the major areas of Timisoara, namely the Iosefin neighborhood, as well as relating it to a number of domains such as infrastructure, population, economy, culture, patrimony through a statistic of losses.

Buildings in the city's historic centers are particularly vulnerable to seismic events. To reduce damage and losses in historic city centers, the seismic vulnerability of buildings needs to be assessed on the ground with approaches that take into account how parameters related to geometric / structural characteristics, seismic deficiencies impact on seismic failure modes.The historical district of Iosefin is one of the 3 districts of Timisoara developed in the 18th century around the main district – Cetate, being a testimony to the evolution of the entire city. Iosefin is located in the southwest part of the city and since the 20th century, it has developed a strong commercial character, especially on the two main arteries – Regele Carol I and 16 Decembrie. The seismic vulnerability assessment was carried out by an empirical method of calculating it, which is particularly suited to historical areas because of its ability to capture heterogeneity and belonging to an ensemble, namely the vulnerability index method, a method applied to a number of 67 buildings.

The outcome of the study has shown that the VIM methodology is not necessarily tailored to the specific seismicity of the city of Timisoara (surface earthquakes), generating probable worse damage than historical records show. Taking into account the age of the investigated buildings and the absence of significant structural damage, we can conclude that the reality is a bit more optimistic about the chance of survival of buildings than the loss scenario resulting from the use of the VIM methodology. Nevertheless, analyzing the results as a whole, it can be noticed that in the case of a seismic intensity event 7 the district can suffer significant losses in several aspects such as: social, economic, cultural-historical, population, built-up, infrastructure.

Keywords: seismic vulnerability, historical buildings, loss scenario, aggregate, seismic evaluation

I. INTRODUCTION

This paper begins presents the seismic vulnerability assessment of 67 buildings in the Iosefin district - Timisoara, an evaluation done by an empirical method of calculating the seismic vulnerability, suitable especially for historical buildings and aras, namely the vulnerability index method (VIM). The result of the application of the method consists in the creation of macroseismic maps a scenario of earthquake synthesized on the area of study. Urban spatial analysis follows, which, overlaid over macroseismic maps, concretises the assessment of seismic vulnerability in several domains - infrastructure, population, economy, social, etc.

II. CONTEXT

Timisoara is one of the biggest cities in Romania, located in the Banat plain. The area in which the city is located is the second most hazardous seismic zone in the country – Banat region, which is subjected to shallow earthquakes, the main particularities of this type being the small depth of the seismic source and a reduce surface of the epicenter area [1].

Beginning with the second half of 1991 a series of unusually strong earthquakes for this area occurred in Banat. Although these earthquakes, due to their limited magnitude, did not have widespread destruction, they were at the level of some of the strongest earthquakes observed in the region over the last two to three centuries. Recently, the Banat seismic events have brought back the high seismicity of the area in question and the need to adopt principles for anti-seismic protection under the specific conditions of the region [2]. If we refer to the city of Timisoara, it can be noticed that the most vulnerable seismic areas are the historical districts, which are built without taking into account antiseismic principles, Iosefin being one of them.Iosefin has developed a strong commercial character since the twentieth century, having various functions, that are still preserved. Assemblies of adjoining buildings with commercial spaces on the ground floor on the two commercial arteries King Carol I and December 16th Boulevard give the character of the area.

III. VULNERABILITY INDEX METHOD (VIM)

Buildings in the city's historic centers are particularly vulnerable to seismic events. To reduce damage and losses in historic city centers, the seismic vulnerability of buildings needs to be assessed on the ground with approaches that take into account how parameters relate to geometric / structural characteristics, seismic deficiencies impact on seismic failure modes. The method used for assessing seismic vulnerability is an empirical method, namely the method of vulnerability index (VIM) introduced by Benedetti and Petrini in 1984 .This approach is to estimate the seismic vulnerability of historic buildings by calculating a vulnerability index as a weighted sum of the specific parameters that most affect the seismic response of a building type [3]. The decision to use this method is due to the capacity of the methodology to capture the heterogeneity of buildings and belonging to an assembly / group of buildings. In the case of the seismic vulnerability assessment of the analyzed buildings in the Iosefin area, the following parameters were used:

1. Vertical structure - organization
2. Vertical structure - materials
3. Location and type of foundations
4. Layout of structural elements
5. Regularity in the plan
6. The vertical Regularity
7. Type of floors
8. Type of roof
9. Details
10. Conservation status
11. Neighboring buildings with different heights
12. Position within the aggregate
13. Number of offset floors
14. Structural homogeneity with neighbors
15. Percentage of openings [3].

The data collected during on-site activity are included in specific forms, validation of the proposed investigation form for assessing the seismic vulnerability of masonry assemblies allowed it to be applied to the entire chosen area, except for buildings whose size and geometric configuration did not allow evaluation without more detailed investigation. The data used to apply the methodologies was collected during specific visual inspections of the area's aggregates.

During this research, the geometric and mechanical properties of 67 buildings, characterized by the number of different floors and types of previous interventions, vertical and horizontal structures, types of roofs, etc. were collected. After the research period, all of the data collected above is organized and placed in a database to provide the geometric and structural characteristics of the built environment to conduct a vulnerability analysis in the selected urban area. This approach consists in estimating the seismic vulnerability of historical buildings by calculating a vulnerability index as the weighted sum of the specific parameters that most affect the seismic response of a building type.

The macroseismic intensity is a description in qualitative terms of the effects of an earthquake in a specific place. The macroseismic intensity translates into a scale of effects, called the Mercalli scale, with intensities from 1 to 12 in the increasing order of their danger.

Based on the possible intensities in the studied seismic area, the probable damage level of a building, a building typology, or a whole area can be determined. This is determined on the basis of Vulnerability Index Methodology, an index that defines the predisposition of a building to be damaged by an earthquake. For each building, depending on the vulnerability index (Iv) and the probable seismic intensity, the µD damage index can be determined based on the equation [4]:

$$\mu_D = 2.5 \cdot \left[1 + \tanh\left(\frac{I+6.25 \cdot V-1\ \ .1}{Q}\right)\right] \quad (1)$$

Where I represents the seismic intensity (between 1 and 12), Q represents a ductility coefficient that takes into account the importance of buildings (Q = 2.3 is considered for masonry buildings with residential or mixed functions), and V represents vulnerability to the building, based on the relationship:

$$\mathrm{V} = 0.46 + 0.0056\ \ \mathrm{Iv} \quad (2)$$

Iv being the vulnerability index previously determined by the VIM method

According to the European macro-earths scale (EMS-98), five levels of probable damage are defined, from DS1 (Damage State 1) to DS5 (Damage State 5), in increasing order of gravity, according to the following table the correspondence between the vulnerability index and the damage level is made through the µD damage index:

µD	Damage state	Most probable degradation level
0.0-1.5	D1	Slight (no structural damage, slight non-structural damage)
1.5-2.5	D2	Moderate (slight structural damage, moderate non-structural damage)
2.5-3.5	D3	Substantial to heavy (moderate structural damage, heavy non-structural damage)
3.5-4.5	D4	Very heavy (heavy structural damage, very heavy non-structural damage)
4.5-5.0	D5	Destruction (very heavy structural damage)

Tab. 1. Correspondence between Vulnerability Index, Damage Level, and Damage Index [4]

Through building data processing, homogeneous groups of buildings have been identified, their main features being displayed in several thematic maps. For each of these groups, the percentage of buildings belonging to a particular subcategory is provided. Maps where for each parameter of the methodology used was assigned to the building a class A, B, C, D are represented in Fig. 1.

After summarizing the results, it was possible to generate a macroseismic map for an earthquake – intensity 7 (Fig. 2).

Following the use of the method, a damage level of 1-5 for each building was obtained, the levels representing seismic risk classes. Synthesizing the values collected for the Iosefin district, we obtain the following results:

LEVEL 1 - 23.9%

LEVEL 2 - 29.85%

LEVEL 3 - 22.38%

LEVEL 4 - 19.4%

LEVEL 5 - 4.47%

Results: The most vulnerable buildings are:

- those that have the highest number of stories;
- those located on the corner of the quartz;
- Those built before 1850, develop on 3-4 floors and have a poor or poor conservation status;
- those that are isolated.

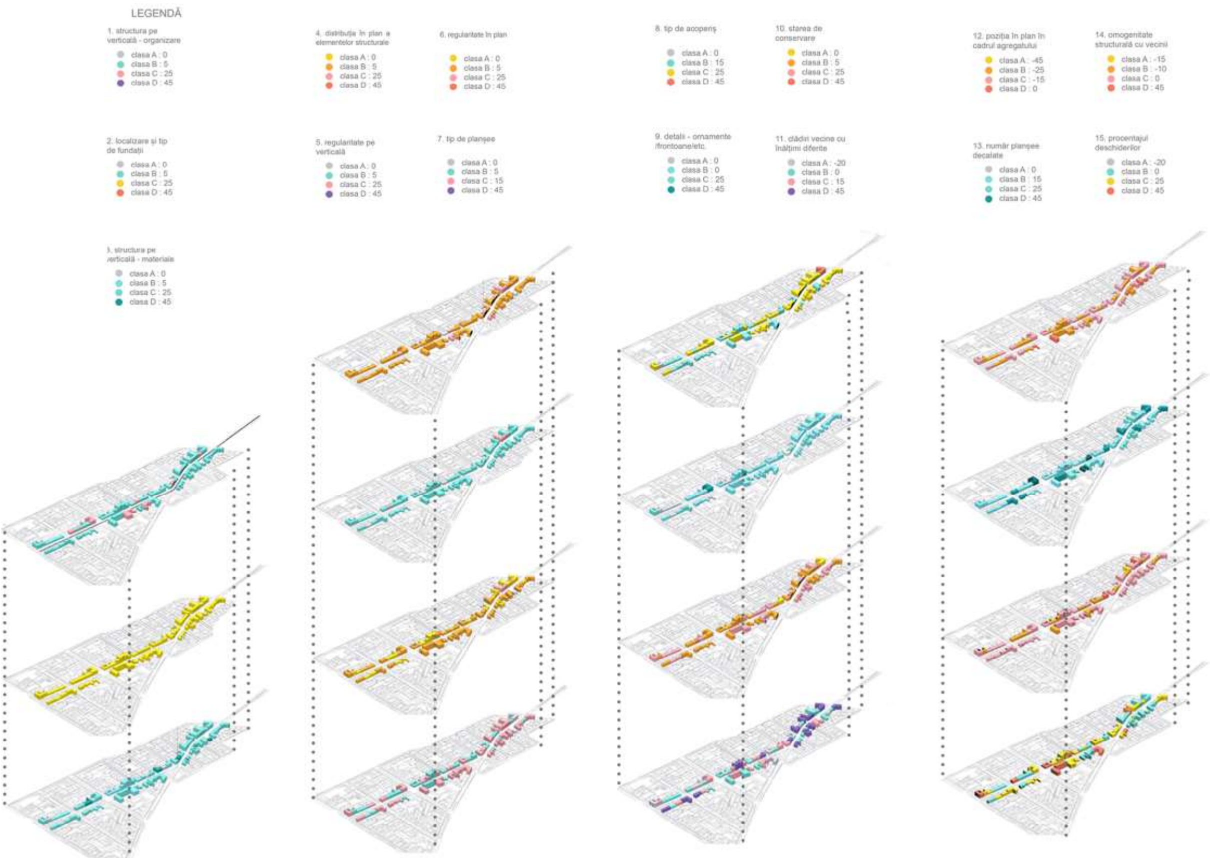

Fig. 1. Thematic axonometries - parameters for VIM

Fig. 2. Macroseismic map for Iosefin

IV. URBAN ANALYSIS

For macro-urban urban analysis, several parameters considered important also for a scenario of losses were taken into account, namely: height regime, occupancy tipology, state of the built-up area, functions and their number as well as the approximate number of jobs and inhabitants.

Through building data processing, homogeneous groups of buildings have been identified, their main features being displayed in several thematic maps. For each of these groups, the percentage of buildings belonging to a particular subcategory is provided. Important construction information is reported on each neighborhood as follows:

- the majority of buildings have one floor (37.31%), while 32.83% of them have 2 floors,

-35% of the total built are corner buildings in the form of L “,” U “

- the majority of the buildings, 76,11%, have a mediocre conservation status, they are not rehabilitated

- the character of the neighborhood is also strengthened by its commercial artery, 85% of the total buildings analyzed dwellings with commercial ground or with various services;

V. LOSS SCENARIO

After urban district analysis, loss scenarios for earthquakes of varying intensity were made, with scenario for intensity 7 being detailed. Based on the probable level of damage, loss scenario for certain urban areas can be made.

1. The total number of unusable buildings after

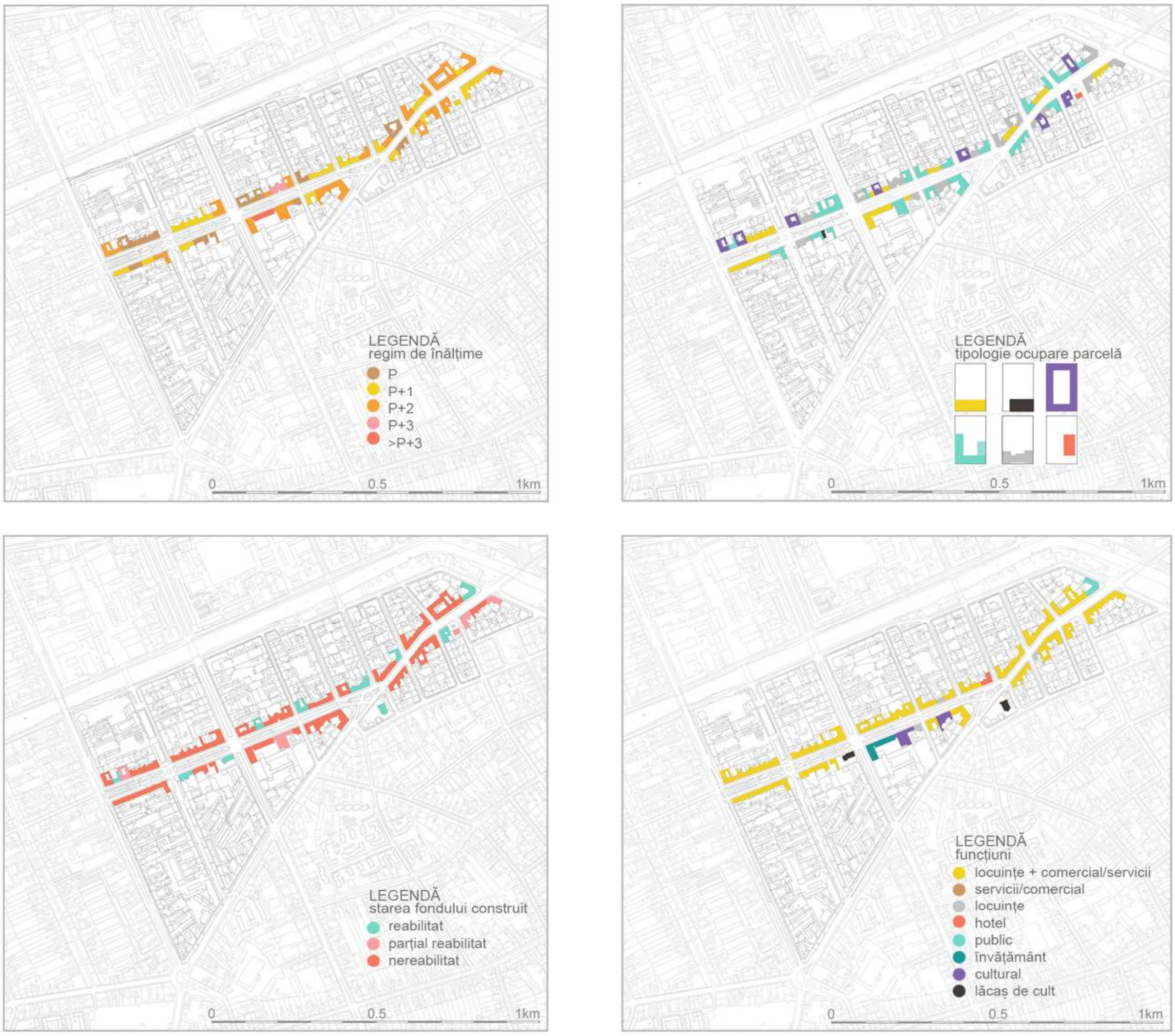

Fig. 3. Iosefin neighborhood maps: height regime, typology occupancy, the state of the built-up area and the functions of the area

the earthquake (UNUSD) is determined :

$$\%MF = 0.9 \times \%H_{MF} + 1.0 \times \%VH_{MF} + 1.0 \times \%D_{MF} \quad (3)$$

$$UNU_{SD} = U_{MF} \times \%MF \quad (4)$$

Where% MF is the overall damage percentage of all buildings, %Hmf, %VHmf, %Dmf are the possible degradation states, UMF being the total number of residential units from total buildings [4].

2. The total number of people who will be homeless is determined on the basis of the relationship:

$$P_{UNU} = P_h \times UNU_{SD} \quad (5)$$

Where Ph is the number of people estimated to be living within each residential unit (average). This estimation can be obtained from statistical institutes or can be determined by calculating and collecting information on the site. [4]

3. The total number of people who will remain unemployed

In this situation, following visual inspections on the study area, the total number of jobs per company (commercial / services) was estimated, which was subsequently distributed on the number of buildings in the area, resulting in an average of jobs /building. The number of job losses is estimated using the same percentage of buildings that become unusable, overlapping the total number of jobs.

4. The total number of persons expected to lose their lives or to be seriously injured shall be determined by:

$$P_{\text{dead and severely injured}} = 0.3 \times P(D_5) \quad (6)$$

Where P (D5) represents the probability in percent that a building / building assembly reaches level 5 damage [4].

5.Another very important aspect is the assessment of financial losses, which could endanger the whole economy and automatically the ability of a city to regenerate after such exceptional events.

$$S_{cost} = \sum_{k=2}^{5} CS(k)$$

$$V_c \sum_{K=2}^{5} \sum_{j=1}^{Ne} [Area(j).\, P_s(k,j).\, RC(k,j)] \quad (7)$$

Where Scost (expressed in thousands of Euros) represents the sum of the repair costs (CS (k)) considered for the state of damage k, Vc represents the cost per unit of measure explained below PS (k, j) is the probability for the building j to be reach the k damage state, and RC is the cost of repair per square meter for each fault condition, considered as a coefficient. Condition 1 is not considered. The area is considered the surface of the first level.

Vc represents the cost per unit of measure, being the actual cost of the building per square meter + the cost of the furniture and equipment in that building and is calculated on the basis of:

$$V_c = GL_c + (n-1).F_C + n.M_C$$

$$F_c = 0.5 \times GL_C \quad (8)$$

Where GLc represents the cost of building a new building at market price, Fc represents the construction cost of a higher level than the basic one (considered 0.5 x GLc), Mc represents the cost of the furniture and equipment, and n represents the number of levels it is also considered the ground floor) [4].

The results obtained for the loss scenario are synthetized in Fig. 4.

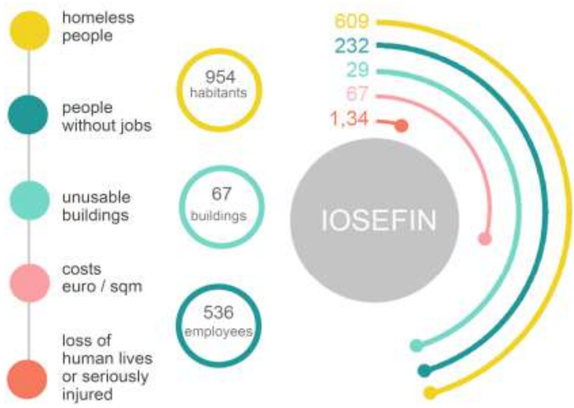

Fig. 4. Results – loss scenario Iosefin

Results: 609 people will be homeless, 232 people will be out of work, 29 buildings are becoming unusable, 67 euro / square meter average repairs, 1.34% of people may lose their lives or be seriously injured

VI. CONCLUSIONS

Analyzing the results as a whole, it can be noticed that in the case of a seismic intensity event 7 the district can suffer significant losses in several aspects such as: social, economic, cultural-historical, population, built-up, infrastructure.

Regarding the built-up fund, it can be noticed that a small number of buildings can reach the state of collapse, but the vast majority of them may suffer medium or severe structural damage, underlining the need for consolidation work to limit the damage. This is particularly important because it directly influences the losses of all the other categories mentioned.

The social impact is the one that will feel the most, influencing both measurable values such as the large number of people who will lose their homes (temporary or even permanent), jobs, family businesses, daily activities, and impossible values to quantify in figures such as: values in the consciousness of the local community, respectively the psychological and emotional impact on the population.

Another issue with major effects on the city is the economic part transposed through financially significant losses generated on the one hand by the physical repair costs of damaged buildings / infrastructure and on the other by the effects of freezing the functions of the city over a certain period time. All these costs must be borne by both owners and users and local authorities who need to be involved throughout the reconstruction process and ensure optimal use of funds and resources through balanced management.

The most important feature of such a study is the identification of possible loss of life. Although the percentages for this scenario appear to be low, transposed over the current situation, they generate unacceptable losses for a modern city, which can only be diminished through a multidisciplinary, phased and properly applied strategy on the high seismic vulnerabilities of Timisoara.

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