The impact of local hazard effects on the vulnerability assessment of an urban area in Timisoara

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ABSTRACT

Timisoara is one of the most important Romanian’s city. Located in the Banat region, it is in a very high seismic zone characterized by earthquakes with small depths and magnitudes not exceeding 5.6 on the Richter scale. In 2021 Timisoara will be the Capital of European Culture and, therefore, the numerous buildings with historical-artistic value in the urban centre must be preserved in terms of seismic safety. Hence, appropriate risk mitigation plans should be planned to assure the integrity of this important cultural heritage under seismic phenomena.

In this framework the proposed study is placed with the aim to assess the seismic vulnerability, by means of a macroseismic approach, of an urban sector of the historical centre of Timisoara, focusing the attention mainly on the influence of geo-hazard phenomena on the its global vulnerability.

First, the application of a vulnerability index based method permits to define the propensity at damage of the buildings sample examined, allowing to plot their typological vulnerability curves according to the EMS-98 scale. Subsequently, the site effects are taken into account in order to define the local amplification factors and, therefore, the amplification of both the expected macroseismic intensity and the global vulnerability of buildings. Finally, a comparison between the damage levels of the inspected sector with and without considering local hazard effects is made.

Keywords: geo-hazard effects, seismic vulnerability, typological vulnerability curves, damage scenario

I. INTRODUCTION

In recent decades, the occurrence of natural disasters has increased exponentially, causing unfortunately a large number of socio-economic losses. In particular, focusing on seismic phenomena, the cyclicity of events has induced a strong interest in the implementation of seismic risk management plans in order to preserve people lives and buildings from collapse [1]. Many earthquakes have been affected by local seismic amplifications, which produced a significant increase of the expected damages. This is due to the stratigraphy of the ground, but also to the poor constructive characteristics of buildings, often not able to face up a certain seismic event, E, with a certain magnitude, MW [2,3]. For this reason, this research aims to investigate the local hazard phenomena in order to safeguard the cultural heritage of a small urban area within the historical centre of Timisoara.

II. ROMANIAN SEISMICITY

Romania is a country located in the Eastern Europe among Danube River, Carpathian Mountain and the Black Sea shore. Romania is characterised by two large and active seismogenic regions, namely Vrancea and Banat. In the first one, there were deep intermediate earthquakes (150 km) with a high number of cycles and a long duration, while the second area, even if in a state of quiescence, is characterized by shallow earthquakes, having a maximum recorded acceleration of 0,20g with a low frequency pulse [4]. In particular, in Timisoara, one of the most important city with many architectural assets, there are two active seismic falls, both in the western part of the city. Several shallow-depth seismic zones, namely East-Vrancea, Făgăraş – Câmpulung, Danubian, Banat and Crişana – Maramureş zones, the Bârlad Depression, the Predobrogean Depression, the Intramoesian Fault and the Transylvanian Depression, are pointed out to study the local seismic hazard of Timisoara [5].

III. SEISMIC VULNERABILITY ASSESSMENT

The seismic vulnerability study aims at assessing the propensity at damage of a sample of buildings following a seismic event. In the historical centre of Timisoara an urban sector made of 11 building aggregates is selected as a case study area for seismic vulnerability evaluation. To this purpose, a rapid procedure for aggregates based on a new vulnerability form analysed in [6,7,8] is used. Buildings are classified from typological and structural points of view according to the Building Typology Matrix (BMT) [9]. The achieved results, shown in Figure 1 in terms of vulnerability index, reveal that this urban sector is composed of M3.1 class masonry buildings with wooden floors (82%), M3.4 masonry buildings with RC floors (9%) and RC buildings (9%). However, the attention is herein focused on masonry buildings only.

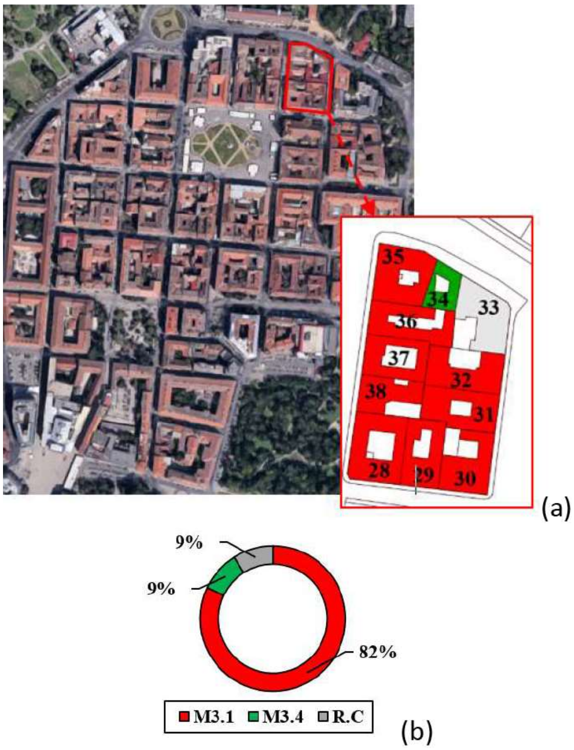


Fig. 1. The studied urban sector (a) and the typological classification of building aggregates (b).

As illustrated in Figure 2, the application of this procedure to the selected urban sector has allowed to evaluate the seismic vulnerability of its masonry compounds.

From the statistical analysis of results, it can be noted that, on average, the expected value of the global vulnerability, VI,G of the entire sector is 0.40 which is associated to an average dispersion, σi,, of 0.02 to. Subsequently, the mean vulnerability curves [10] are obtained to estimate the propensity at damage of the analysed building classes (Fig. 3). These curves express the probability P[SL|IEMS-98] that a building reaches a certain limit state "LS" at a given intensity "IEMS-98" according to the European macroseismic scale (EMS-98) [11]. In particular, these curves depend on three variables: the vulnerability index (VI), the seismic hazard expressed in terms of macroseismic intensity (IEMS-98) and the ductility factor Q, which describes the ductility of a certain typological class (ranging from 1.0 to 4.0) [12].

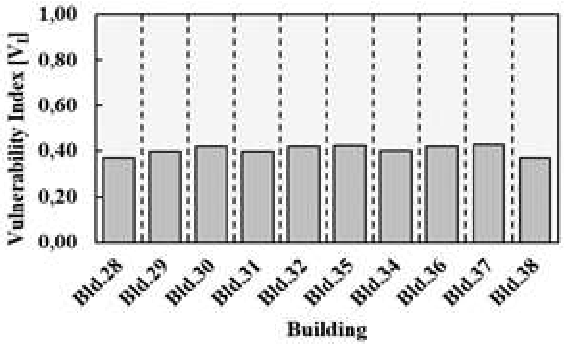


Fig. 2. Vulnerability analysis results.

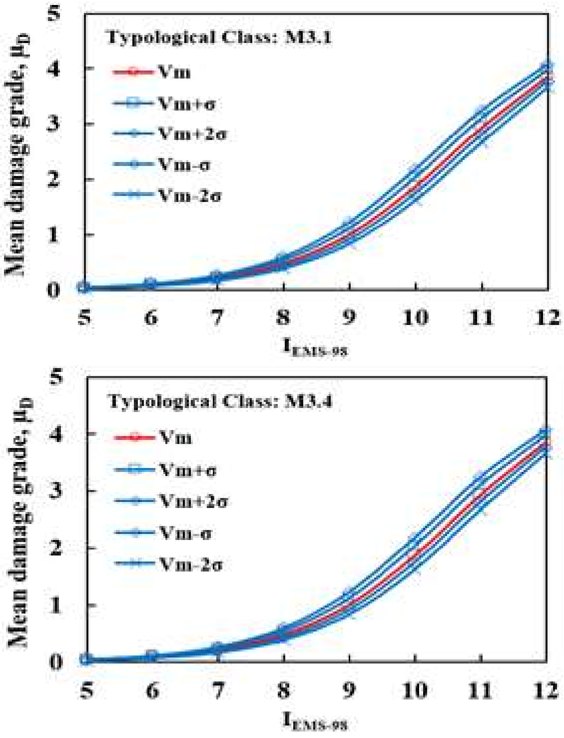


Fig. 3. Vulnerability curves of class M3.1 (a) and class M3.4 (b) buildings.

IV. IMPACT DAMAGE SCENARIOS

A forecast of the possible damage scenarios induced by seismic events is a useful tool for a predictive quantitative definition of expected losses and for the consequent implementation of mitigation measures. Here the Gutenberg-Richter law [13] is used to predict theoretically the number of magnitudes that can occur in the inspected area. So, a range of magnitudes, based on the historical earthquakes occurred, are selected in the range [4÷6]. The cumulative distribution function, FM (m) (see Eq.(1)), estimated according to [14], is reported in Fig. 4. where mmax and mmin are respectively the maximum moment magnitude and the minimum one previously considered.

$$F_M(\mathrm{m}) = \frac{1-10^{-b(m-m_{\min})}}{1-10^{-b(m_{\max}-m_{\min})}} \qquad (1)$$

Based on these considerations, varying the epicentral distances, R, in the range 5÷15 Km, the EMS98 macro-seismic intensities are determined on the basis of the following Eq. (2) [15]:

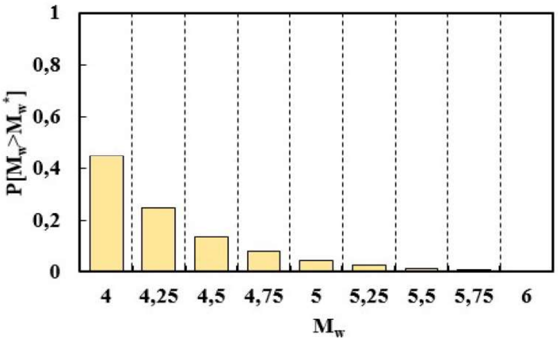


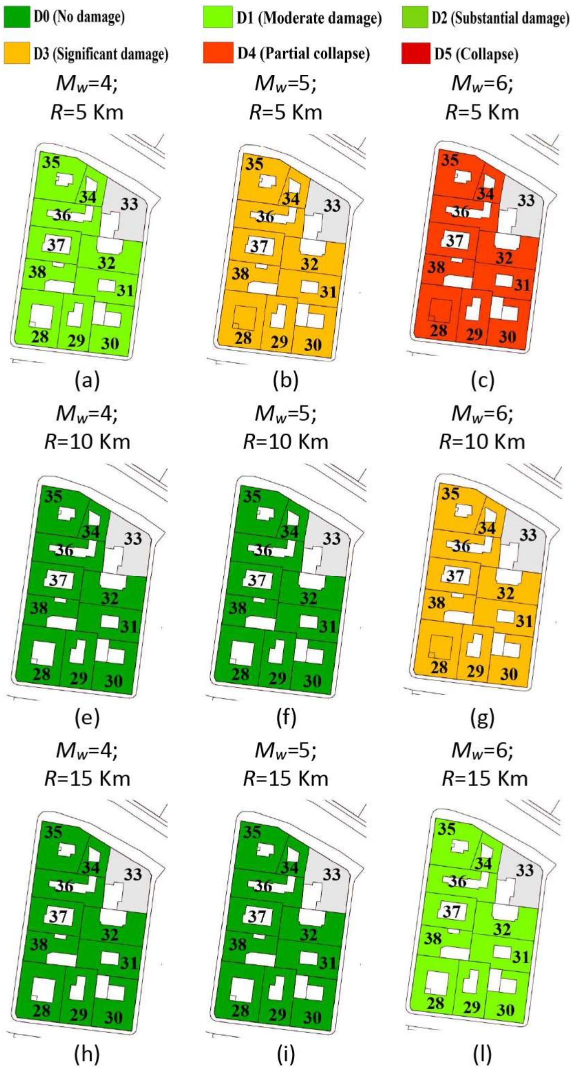
Fig. 4. Moment magnitude distribution based on Gutenberg-Richter law for the examined source.

$$I_{EMS-98} = 1.45M_w - 2.46\ln(R) + 8.166 \qquad (2)$$

Mw	R [Km]	IEMS-98
4	5	10
5		11
6		12
4	10	8
5		9
6		11
4	15	7
5		8
6		10

Table 1 . Correlation between magnitude, Mw, and macroseismic intensity, IEMS-98, for different epicentral

Therefore, different damage scenarios are obtained for diverse magnitudes and epicentral distances (Fig. 5).



(a) (b) (c)

(e) (f) (g)

(h) (i) (l)

Fig. 5. Seismic damage scenarios for different moment magnitudes and epicentral distances.

As expected, it is apparent that the worst case is when R=5 Km. In this case, varying the magnitude from 4 to 6 and, the expected damages tend to increase from moderate to partial collapse.

On the other hand, for R=10 Km and R=15 Km the maximum expected damage at the maximum magnitude considered is of significant level and moderate one, respectively. Furthermore, for epicentral distances greater than 5 Km and under magnitudes of 4 and 5, the expected damage is absent. However, since buildings have similar vulnerability index, it is worth nothing that, in all the cases, the damage distribution is uniform in the investigated urban sector.

V. GEO-HAZARD EFFECTS

The macroseismic intensity is the main parameter for correlating the seismic input to damage deriving from post-earthquake scenarios and/or its prediction as well.

However, it is important to take into account both the interaction effects among buildings and the soil type in order to evaluate the increases in terms of global vulnerability and, therefore, of the damage induced. The macroseismic intensity increment induced by geological site phenomena are derived from the period-amplification effects dependence. In particular, referring to a generic design elastic spectrum, according to the design code [17], the local amplification factor fag is defined as the ratio between the maximum acceleration of the elastic spectrum evaluated for a generic soil class (K), Sae(T)K, and the elastic response spectrum on the bedrock, Sae(T)B, see Eq. (3).

$$f_{ag} = \frac{S_{ae}(T)_K}{S_{ae}(T)_R} \tag{3}$$

Subsequently, the macroseismic intensity increase, ΔI, has been determined according to Eq. 4:

$$\Delta_I = \frac{\ln\,(f_{ag})}{\ln C_2} \tag{4}$$

where the coefficient C2, equal to 1.82, represents the PGA increment produced by macroseismic intensity according to the correlation law proposed in [16]. Finally, the seismic vulnerability increase connected to local site phenomena, ΔV, is always defined in [16] and is calculated as follows:

$$\Delta_V = \frac{\Delta_I}{6.25} \tag{5}$$

Referring to the case study, the soil category “C” is considered and the corresponding spectrum according to EC8 [17] is plotted in Fig. 6.

Based on these considerations, the vibration period associated to the inspected building samples is calculated according to the simplified formulation envisaged by EC8 [17] as follows:

$$T_i = \alpha H^{\beta} \tag{6}$$

where H is the total height of buildings and the coefficients, α and β, are respectively, 0.05 and 0.75. The local amplification effect results for buildings developed on one and two floors are presented in Table 2.

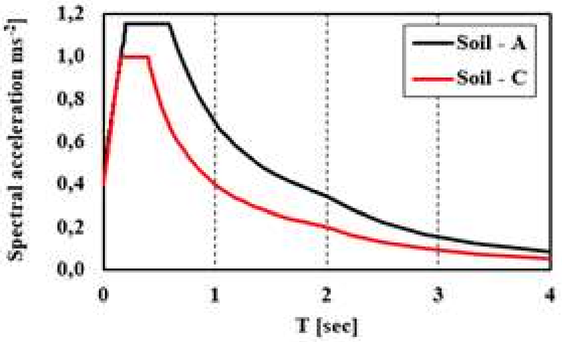


Fig. 6. EC8 elastic spectra for different soil conditions.

Floors	T_i [s]	$S_{ae}(T)_C$ [ms^{-2}]	$S_{ae}(T)_A$ [ms^{-2}]	f_{ag}	Δ_I	Δ_V
1	0.13	0.89	0.9	1.00	0.02	-
2	0.22	1.15	1.00	1.20	0.23	0.04

Table 2. Amplification factor for different classes of buildings.

It is worth noting that, depending on the class of buildings [18], the seismic intensity amplification due to the soil type is increased by 2% and 23% for single-storey buildings and two-storeys ones, respectively. This produces a negligible increase of Δvulnerability for single-storey buildings, while V= 0.04 is achieved for two-story buildings.

The global vulnerability for the analysed building typologies can be calculated as the sum of the normalized vulnerability index and the local effects [16], as shown in Eq. (7):

$$\bar{V}_I = V_I + \Delta V_I \qquad (7)$$

The results reported in Fig. 7 show how the effect induced by local phenomena increases the global vulnerability of about 10%, with an average value, VIm, of 0.44, compared to the condition where the geo-hazard effects are neglected. The illustration of the expected damages due to local site effects is depicted in Figure 8, where the typological vulnerability curves of the investigated building classes are shown.

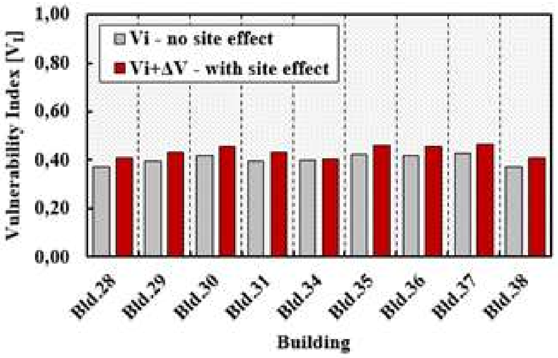
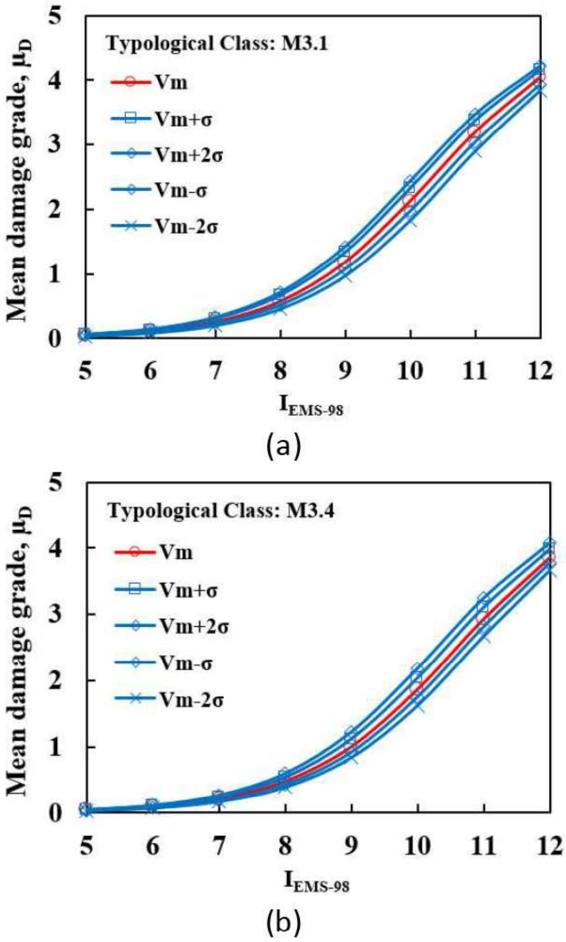


Fig. 7. Vulnerability distribution in the urban sector also considering local hazard effects.



(a)

(b)

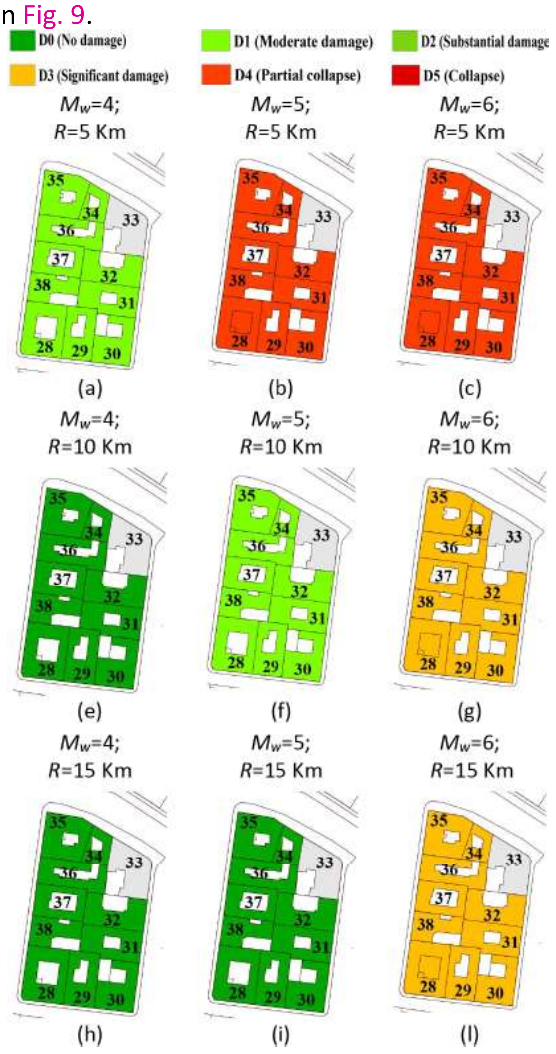
Fig. 8. Vulnerability curves of investigated building classes considering local hazard effects.

Thus, as in Section 4, it is possible to define the correlation between moment magnitudes and amplified macroseismic intensities taking into account local amplification phenomena (Table 3).

M_W	R [Km]	I_{EMS-98}
4	5	10
5		12
6		12
4	10	9
5		10
6		11
4	15	8
5		9
6		11

Table 3. Link between magnitude and macroseismic intensity considering geo-hazard increments for different epicentral distances

The new damage scenarios resulting from considering local amplification effects are indicated in Fig. 9.



The comparison of achieved results with the previous ones show that local amplification effects increases significantly the expected damages in the examined urban sector. This occurs especially at the shortest epicentral distance (5 Km), where the partial collapse is attained also with Mw=5.

VI CONCLUSIONS

The paper analysed the seismic vulnerability of a historic heritage urban sector within the city of Timisoara using a probabilistic approach. The study conducted allowed to characterise the seismicity of the study area taking into consideration local effects. Concerning the definition of damage scenarios, the Gutenberg-Richter law was used. In particular, it was possible to define the discrete distribution of the magnitude (Mw) and the relative probability of occurrence. In this context, a parametric analysis was performed varying magnitudes and epicentral distances in order to predict the expected seismic damages for masonry aggregates of the investigated area. However, from the achieved results it is worth noting that, for moderate values of seismic intensity (IEMS-98<X) the expected damage is not relevant for all the analysed buildings, whereas for high values of seismic intensity (X≤IEMS-98≤XII), the expected damage would cause an incipient collapse of the analysed sample.

Subsequently, seismic amplification due to geo-hazard phenomena were considered in order to take into consideration the increased effects in terms of both macroseismic intensity and global vulnerability. More in detail, the amplification factor, fag, was defined, it depending on the class of soil considered. In particular, for a type of soil “C”, fag was equal to 1.00 and 1.20 for single-storey buildings and two-storey ones, respectively. Thus, it was shown how local effects provides an increment from 2% to 23% of the seismic intensity associated to the typological classes identified. This circumstance caused an increase of the expected damage approximately of 12% for IEMS-98≥X, with damage thresholds equal to D4 (partial collapse) for Mw equal to 5 and 6 and in case of R= 5 Km. Similarly, for R= 10 Km and 15 Km, in case of Mw=6 the maximum expected damage was D3 (significant damage), with an estimated increase of 10% compared to the case where site effects were neglected. In addition, it was observed that there is an average increase of the global vulnerability induced by local site effects of 4% for two-storeys buildings, with an expected mean value of 0.44, while this effect was null for single-storey buildings. Finally, the representation of the global vulnerability was also obtained through typological vulnerability curves, which show how the local effects progressively affect the damaging effect of the classes of buildings examined during seismic events.

REFERENCES

[1] F. Pavel, R. Vacareanu, J. Douglas, M. Radulian, C. Cioflan, and A. Barbat, “An Updated Probabilistic Seismic Hazard Assessment for Romania and Comparison with the Approach and Outcomes of the SHARE Project,” Pure and Applied Geophysics, 2016, pag. 1881-1905.

[2] A. H. Barbat, M. L. Carreño, L. G. Pujades, N. Lantada, O. D. Cardona, and M. C. Marulanda, “Seismic vulnerability and risk evaluation methods for urban areas. A review with application to a pilot area,” Structure and Infrastructure Engineering, 2010, pag. 17-38.

[3] N. N. Ambraseys and J. Douglas, “Near-field horizontal and vertical earthquake ground motions,” Soil Dynamics and Earthquake Engineering, 2003, pag. 1-18.

[4] E. Oros, “The Seismotetctonic Database for Banat Seismic Region – The Catalogue of Focal Mechanism Solutions and the Digital Tectonic and Geologic Regional Maps,” 2004, pag. 965-967.

[5] V. Y. Sokolov, F. Wenzel, and R. Mohindra, “Probabilistic seismic hazard assessment for Romania and sensitivity analysis: A case of joint consideration of intermediate-depth (Vrancea) and shallow (crustal) seismicity,” Soil Dynamics and Earthquake Engineering, 2009, pag. 364-381.

[6] A. Formisano, G. Florio, R. Landolfo, and F. M. Mazzolani, “Numerical calibration of an easy method for seismic behaviour assessment on large scale of masonry building aggregates,” Advances in Engineering Software, 2015, pag. 116-138.

[7] A. Formisano, N. Chieffo, and M. Mosoarca, “Seismic Vulnerability and Damage Speedy Estimation of an Urban Sector within the Municipality of San Potito Sannitico (Caserta, Italy),” The Open Civil Engineering Journal, 2017, pag. 1106–1121.

[8] A. Formisano, N. Chieffo, F. Fabbrocino, and R. Landolfo, “Seismic vulnerability and damage of Italian historical centre: a case study in the Campania region,” in AIP Conference Proceedings, 2017.

[9] S. Lagomarsino and S. Cattari, “PERPETUATE guidelines for seismic performance-based assessment of cultural heritage masonry structures,” Bulletin of Earthquake Engineering, 2015.

[10] S. Giovinazzi and S. Lagomarsino, “A Macroseismic metod for the vulnerability assessment of buildings,” in 13th World Conference on Earthquake Engineering, 2004.

[11] G. Grünthal, European Macroseismic Scale 1998. 1998.

[12] S. Lagomarsino, “On the vulnerability assessment of monumental buildings,” Bulletin of Earthquake Engineering, 2006, pag. 445-463.

[13] S. G. Wesnousky, “The Gutenberg-Richter or characteristic earthquake distribution, which is it?,” Bulletin of the Seismological Society of America, 1994, pag. 1940-1959.

[14] J. W. Baker, “An introduction to Probabilistic Seismic Hazard Analysis (PSHA),” White Pap, 2008.

[15] N. Chieffo, M. Mosoarca, A. Formisano, and I. Apostol, “Seismic vulnerability assessment and loss estimation of an urban district of Timisoara,” in 3rd World Multidisciplinary Civil Engineering, Architecture, Urban Planning Symposium, 2018, pag. 1-10.

[16] S. Giovinazzi, “Geotechnical Hazard Representation for Damage Scenario and Seismic Risk Analysis,”2007, pag. 221–234.

[17] Eurocode 8, “European Standard EN 1998-3:2005: Design of structures for earthquake resistance - Part 3: Assessment and retrofitting of buildings,” Comite Europeen de Normalisation, Brussels, 2005.

[18] I. Apostol, M. Mosoarca, and N. Chieffo, “Seismic vulnerability scenarios for Timisoara, Romania,” 2018, pag. 1191-1200.