16th World Conference on Earthquake, 16WCEE 2017

Santiago Chile, January 9th to 13th 2017

Paper N° 2436 (Abstract ID)

Registration Code: S- J1463652023

SEISMIC VULNERABILITY ASSESSMENT FOR RESIDENTIAL BUILDINGS IN OSIJEK, CROATIA

M. Hadzima-Nyarko[(1)], M. Lešić[(2)], D. Morić[(3)]

[(1)] *Assistant Professor, Faculty of Civil Engineering in Osijek, mhadzima@gfos.hr*
[(2)] *Univ.bacc.ing.aedif., Faculty of Civil Engineering in Osijek, le.marija@gmail.com*
[(3)] *Associate Professor, Faculty of Civil Engineering in Osijek, dmoric@gfos.hr*

Abstract

This paper deals with 100 residential buildings from many parts of Osijek, the fourth largest city in Croatia, all built between 1962 and 1987. The aim of this paper is to provide the first steps in assessing seismic risk in Osijek, which has been achieved through an investigation of the building typology by site investigation and existing plans and documentation. Apart from the data about the main building types, some additional parameters, such as geographical location, position in the block, plan view geometry, number of storeys, built-up area, the age of buildings, structural system, main construction material and the number of occupants are also collected.

These parameters are important for determining the seismic vulnerability of existing buildings as an element of seismic risk, i.e. the probability of loss at a given site obtained through the convolution of exposure, vulnerability and seismic hazard. The macroseismic approach for seismic vulnerability methodology is provided. Vulnerability class is defined for each building after identifying the building's primary structural system and building damage assessment is carried using vulnerability index method. The resulting vulnerability of the considered residential buildings provides insight necessary for emergency planning and for identification of critical objects vulnerable to seismic loading.

Keywords: Seismic Vulnerability Assessment; Building typology; Vulnerability Index Method

1. Introduction

Although Croatia is located in an earthquake prone area (it is at risk from earthquakes producing ground accelerations ranging up to 0.38*g*), there is only a need for analysis of metropolitan areas with significant seismic risk. More than half of the Croatian territory (56.22%) with more than one third (1,633,529) of the total Croatian population is classified as a high-risk seismic zone.

Most of the buildings built in the last decade are in accordance with Eurocode 8 provisions for earthquake-resistant design concepts. However, a significant number of older stone and masonry buildings are not in accordance with any of these provisions. The seismic risk assessment and seismic vulnerability assessment of existing building stock is essential for establishing priorities in a long-term prevention policy.

Osijek, with a population of 108,048 in 2011, is the fourth largest city in Croatia and is the largest city of the eastern Croatian region of Slavonia. The east of Croatia is a seismic area with intensity VII; based on previous seismic maps, the intensity was estimated as VIII, i.e., it is exposed to possible destructive and very strong earthquake.

This paper deals with older buildings from parts of the city of Osijek. Through data and documentation collection, a database of 100 buildings is built. Vulnerability index method uses collected information of parameters of the building (plan, height, type of foundation, structural and non-structural elements, type and quality of materials). This method is used as one of several general methodologies for vulnerability assessment and seismic risk assessment. It is an ‘indirect’ method in which, through the vulnerability index, the relationship between seismic action and the response is obtained.

2. Study area

Osijek is the fourth largest city in Croatia and it is the largest city in Slavonia with a population of 108,048 (according to the 2011 census) and an area of 171 000 m^2 (with suburbs). The city is located along the banks of the river Drava (Fig. 1) at an elevation of 90 meters. The history of its name, according to interpretations of Croatian historiography, comes from the Croatian word "oseka" which means "ebb tide". The name was given to the city due to its position on elevated ground which prevented the city from being flooded by local swamp waters, so it was favorable for settlement. Under the influence of Hungarian language, in historical documents the city was referred to as Eszek or Ezeek. Fig. 2 shows a panorama of Osijek with a view of Gornji grad (Upper town), with the cathedral as the most prominent detail of the city, and the old part of town called Tvrđa.

Fig. 1 – Geography view of Osijek with selected buildings

Fig. 2 – Aerial view of Osijek (www.tzobarzup.hr)

3. Seismic hazard

Seismic hazard is presented with two maps for Croatia [1], which are accepted as a part of the National Annex to EN 1998-1. Hazard is expressed in terms of the peak horizontal ground acceleration which is exceeded on average once in 95 or 475 years. Fig. 3 shows the map where the reference peak ground acceleration of type A for the return period of 475 years has a probability of exceedance of 10% in 50 years. According to EN 1998-1, soil type A is defined as the ground where the velocity of propagation of seismic waves exceed $v > 800$ m/s and is composed of rock or other rock-like geological formations, including at most 5 meters of weaker material at the surface.

According to this seismic hazard map for Croatia (Fig. 3), the peak horizontal ground acceleration for the city of Osijek is 0.11*g*.

4. Selected buildings

This paper processes 100 building from Osijek’s area, as is shown in Fig. 1. In order to create a database, forms were filled with data on buildings which were later used in seismic damage and loss evaluation calculation. The necessary entries in the forms were:

- general data: purpose of the building and year of construction, number of people in the household,
- location of the building, orientation, position relative to the block,
- geometrical attributes: layout dimensions, gross and net area, layout regularities, number of storeys, storey height and height of the buildings.

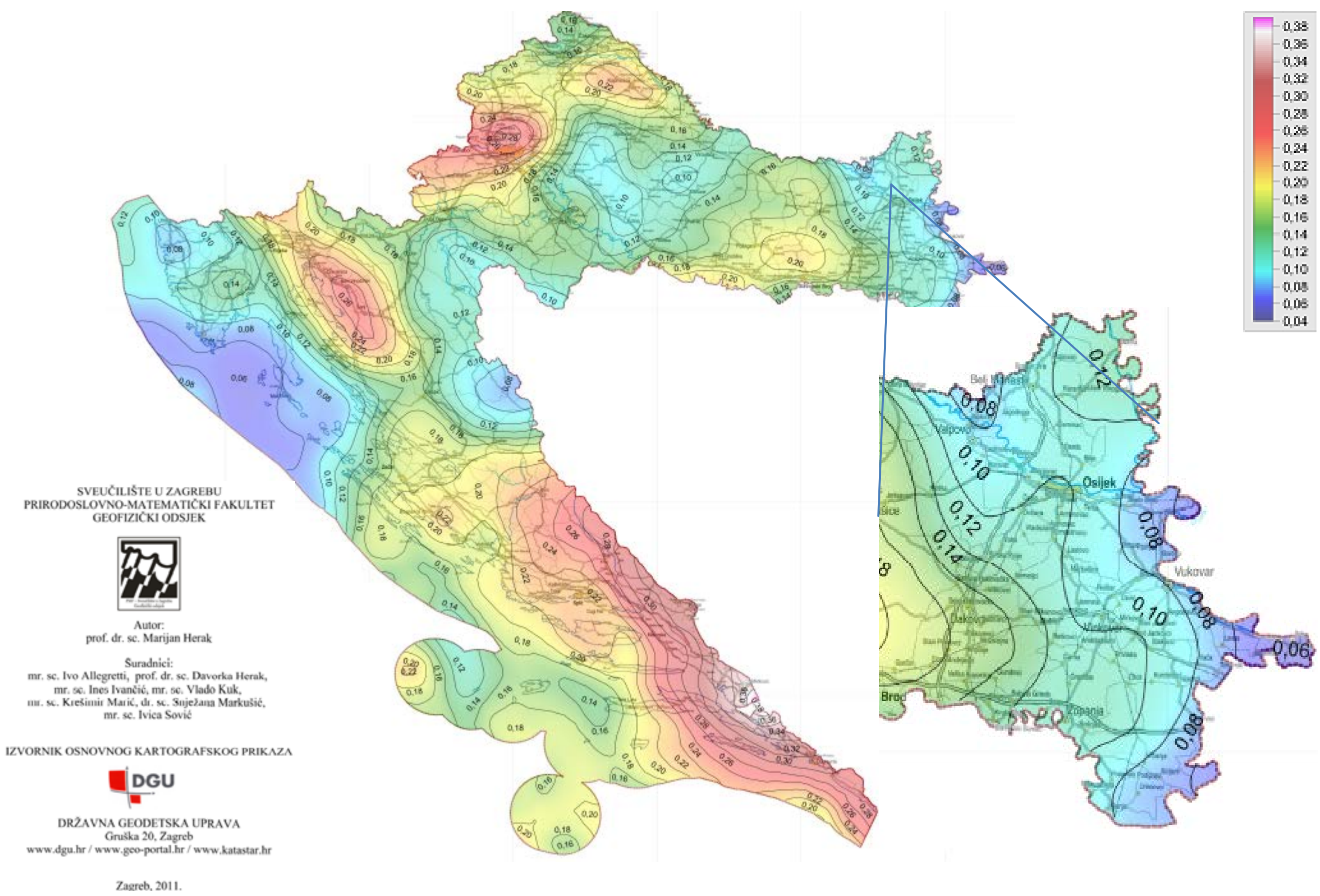


Fig. 3 – Seismic hazard map for Croatia [1]

All the buildings in the database were built in the second half of the 20 century, i.e., from 1962 to 1987. Of the 100 buildings in the database, 86 of them are confined masonry (masonry walls with horizontal and vertical RC confining members), 4 of them are reinforced concrete (RC) moment frames with RC shear walls (RC dual system) and 10 of them belong to RC shear walls (RC SW) (Table 1). The floor constructions are built as semi prefabricated elements or as RC floors. During the other half of the ’70-s, RC floors were used slightly more often. The number of storeys in the database varied from 2 to 12 floors. The highest building is located in Vijenac Murse; having 12 storeys and a total height of 37.1m.

Floor heights vary from 2.5 to 2.9 m, with most of the buildings in the database having a storey height of 2.8 m. As it can be seen from Fig. 4, most buildings in the database are confined masonry buildings having three, five or seven floors, and were built mainly before any seismic codes.

Table 1 – Representative building types in the database

Number of storeys	Number of buildings	Structural type
2	3	Confined masonry
3	18	Confined masonry
4	1	Confined masonry
5	57	Shear walls (9)
		Confined masonry (48)
6	3	Confined masonry
7	10	Confined masonry
10	4	Dual (1)
		Confined masonry (3)
11	1	Shear walls
12	3	Dual
ALL	**100**	

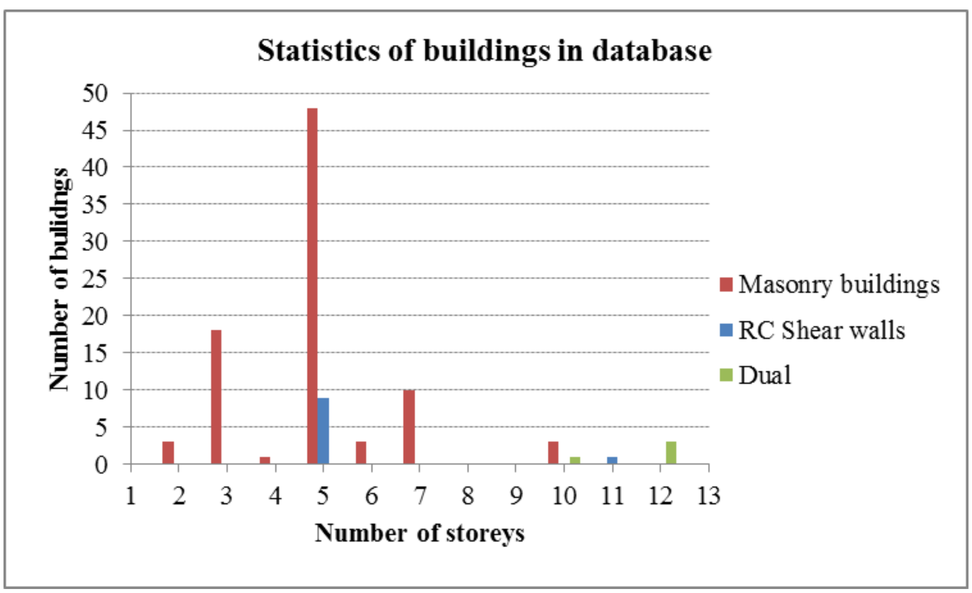


Fig. 4 – Building statistics with respect to number of storeys

5. Methodology

In this section, the European Macroseismic Scale (EMS-98) is described [2] and the vulnerability index and damage functions methodology from the works of Bernardini [3] and Giovinazzi [4] are adopted. In this method, the value of the vulnerability index can be changed depending on the structural systems, quality of construction etc. by introducing behavior and regional modifiers which are based on expert judgements. Since there are is no available data of damaged buildings under earthquake loading in our country, we will propose behavior modifiers based on values suggested by earlier works and on judgement based on available project documentation of the considered buildings. Dependent on the proposed modifiers, the seismic vulnerability of existing buildings in the city of Osijek will be assessed.

5.1 EMS vulnerability classes

The introduction of vulnerability classes in EMS-98 enables one to differentiate the ways in which structures respond to earthquake. An improvement over previous scales, which relate construction type to vulnerability, is the attempt to categorize seismic resistance of buildings in a way that takes into account the type of building and other factors such as construction, state of preservation and regularity, thereby resulting in a table of vulnerability values.

Another advantage of EMS-98 is the existence of transition classes (class ranges) which take into account the influence of factors on the vulnerability values as well as vulnerability range values that can be used to denote the dispersion of existing knowledge and to show the probability of expectations using simple graphical elements.

EMS-98 distinguishes between the following building types for masonry structures: rubble stone, adobe, simple stone, massive stone, two types of unreinforced structures: with manufactured stone units and with RC floors and reinforced or confined masonry structures. For RC buildings, EMS-98 distinguishes frame and wall systems with different levels of earthquake resistance design (ERD), which assume that buildings in an earthquake zone are designed and built for an earthquake of given intensity, matching site and soil conditions of the respective zone [2]. The different design levels represent different levels of ground motion or base shear coefficient [5].

Depending on the levels of quality and workmanship, state of preservation, regularity and other vulnerability affecting parameters, the vulnerability class has to be assigned. Schwarz et al. [5] reinterpreted the situation after the 1978 Albstadt earthquake and elaborated empirical vulnerability functions of the still existing masonry type buildings with respect to the composition of building types, their construction and age, the observed behavior and damage. Under investigation were two and three storeyed unreinforced masonry buildings (URM): with floors of timber beam constructions and with RC floors. They concluded that, based on the EMS-98 vulnerability table, the observed shaking effects with respect to quality and quantity of damage cases (I_{obs}) refer to a calculation value of intensity I_{EMS} = 7.0 to 7.25, which is lower than that one given in recent earthquake catalogues (VII-VIII). In other words, their main conclusion was that the resistance of the masonry buildings is underestimated by the assigned vulnerability classes [5]. They also concluded that the results can be transferred to unreinforced masonry buildings in countries with similar construction tradition.

Therefore, based on their conclusion, and the fact that the EMS table values of vulnerability are underestimated for safety reasons, we allocated a vulnerability class to our buildings. Considering the most probable vulnerability class for confined masonry is D, but, taking into account buildings with 7 to 10 storeys (Fig. 4), we consider/assume that such buildings have reduced seismic resistance.

We attempt to solve this problem using the vulnerability index method, which is explained in the following section, and with which we tried to take into account behavior and regional vulnerability factors, in order to attain a better assessment of seismic vulnerability values.

5.2 Vulnerability index method

The Vulnerability Index Method (VIM) is the institutional method for defining vulnerability at national level in Italy approved by the Gruppo Nazionale per la Difesa dai Terremoti – GNDT in 1993. It was first proposed by Benedetti and Petrini in 1984 [6] and then validated on large samples by Benedetti et al. in 1988 [7]. VIM uses the collected information and parameters which influence the building vulnerability (plan, type of foundation, structural and non-structural elements, type and quality of materials). The method is called 'indirect' because through the vulnerability index, obtained by combination of data from different building typologies in a specific area collected by observation in situ, the relationship between seismic action and the response is obtained. The seismic action has to be defined in terms of macroseismic intensity and the seismic quality of the buildings has to be described by means of a vulnerability index.

To evaluate the vulnerability evaluation for each building, we followed the vulnerability index method as the initial vulnerability assessment approach in this study, as was proposed by Milutinovic and Trendafiloski [8]. We also used the EMS-98 vulnerability approach to aid in the interpretation of results. Therefore, structural typology, age and other characteristics (such as regularity, position...) of the buildings were considered. The first step was to define a building typology and then assign average vulnerability indices to the vulnerability classes according to how Milutinovic and Trendafiloski [8] propose. As part of the Project Risk-UE, Report 4: Vulnerability of current buildings, 23 building classes were defined: 10 classes for masonry (M), 7 for reinforced concrete (RC), 5 for steel (S) and 1 for wooden (W) buildings. The main building typologies found in our database with the representative values of vulnerability indices have been defined (Table 2): the most plausible value for the specific building type V_I^* (the typological vulnerability index) is computed as the centroid of the membership function; V^- and V^+ are evaluated by a 0.5-cut of the membership function, representing the bounds of the plausibility range of V_I^* for the specific building type. V_{min} and V_{max} correspond to the upper and lower bounds of the possible values of the final vulnerability index value, for the specific building type.

The vulnerability index of every building does not only depend on the behavior of its structural system, but it involves other factors as follows [4]:

$$V_I = V_I^* + V_r + V_m \, , \tag{1}$$

where V_R is the regional vulnerability modifier and $V_{m,}$ is the behavior modifier.

5.1.1 The impact of behavior and regional vulnerability modifiers on the vulnerability index

The identification of behavior modifiers was made empirically, on the basis of the observation of typical damage pattern, taking into account also what was suggested by several Inspection Forms [7] and by the previous proposal of [9]. The modifying scores are attributed on the basis of expert judgment although they have been partially calibrated by the comparison with previous vulnerability evaluation [10].

For every building, we added behavior modifier factors according to the proposal of Milutinovic and Trendafiloski [8] and extended with Lantada et al. [11], which are presented in Table 3. The only difference is that for Aggregate building position we used the same values for corner and header buildings (+0.04). Isolated building blocks consisted of two or three connected buildings and make up more than half of the database. Therefore, for a block of two buildings, the behavior modifier for both was assumed to have a value of +0.04.

Table 2 – Vulnerability index values for buildings typologies found in this study [8]

Typology		**Description**	**Vulnerability indices**				
			V_{Imin}	V_I^-	V_I^*	V_I^+	V_{Imax}
Masonry	M4	Reinforced or confined masonry walls	0.14	0.33	0.451	0.633	0.70
Reinforced concrete	RC2	Concrete shear walls	-0.02	0.047	0.386	0.67	0.86
	RC4	RC Dual systems (RC frame and wall)	-0.02	0.047	0.386	0.67	0.86

For blocks of three buildings, the behavior modifier for building in the middle was 0.00, while the neighboring buildings were +0.04. The modifier – façade length – was considered only for masonry buildings.

A regional vulnerability factor V_r takes into account building typologies at a regional level which affects vulnerability due to traditional constructive techniques in different regions. The range boundaries are quite large in order to be representative of the huge variety of the constructive techniques used all around the different European Countries. Regional vulnerability factor V_r is allowed to modify the $V_I{}^*$ typological vulnerability index on the basis of expert judgment or on the basis of available historical data. An expert judgment must be the result of precise technological, structural, constructive information of better or worse average behavior with regard to the one proposed. When data about observed damages exist; the average curve can be shifted in order to obtain a better approximation of the same data.

According to Oliveira [12], the value of V_r =0.12 is applied for Massive Stone typology in Lisbon and could provide a better behavior than the proposed average one.

The values of the regional vulnerability factor ranging from 0.08 to 0.16, depending on the years of seismic codes and structural types, were proposed by Feriche el al. [13] from the analysis of damaged buildings after the Lorca 2011 earthquake.

Also, regional vulnerability factors for masonry buildings for masonry types built of simple stone (M3M) are proposed with a value of 0.25, for pre-code low rise and mid-rise masonry buildings with RC floors (M6LPC and M6LMC) 0.15 and 0.12 respectively and for RC buildings 0 [14].

Table 3 – Behavior modifiers according to Milutinovic and Trendafiloski [8] and extended with Lantada et al. [11]

	Description of behavior modifiers				Value
1.	State of preservation	1.1.	Very good maintenance	<10 years	-0.04
		1.2.	Good maintenance		0
		1.3.	Bad maintenance	>40 years	0.04
2.	Plan irregularity	2.1.	Regular		0
		2.2.	Irregular		0.04
3.	Vertical irregularity	3.1.	Regular		0
		3.2.	Irregular		0.02
		3.3.	Soft-story		0.04
4.	Roof	4.1.	Light		0
		4.2.	Heavy		0.04
5.	Soil morphology	5.1.	Flat		0
		5.2.	Slope		0.04
6.	Aggregate building position	6.1.	Isolated		0
		6.2.	Middle		-0.04
		6.3.	Corner		0.04
		6.4.	Header		0.06/
7.	Aggregate building elevation	7.1.	Adjacent buildings at same level		0
		7.2.	Adjacent buildings higher		-0.04
		7.3.	An adjacent building higher and the other at same level		-0.02
		7.4.	An adjacent building lower and the other at same level		0.02
		7.5.	Adjacent buildings lower		0.04
		7.6.	An adjacent building lower and the other higher		0.02
8.*	Façade length	8.1.	L<15m		0
		8.2.	L>15m		0.04
9.	Number of floors	9.1.	Low	1 or 2	-0.02
		9.2.	Medium	3, 4 or 5	0.02
		9.3.	High	≥6	0.06
* for masonry buildings				V_m=	$\Sigma V_{m,k}$

Therefore, based on the aforementioned, we proposed values of 0.08 for confined masonry and 0 for RC buildings.

It is convenient to translate the V_I estimates obtained so far into the vulnerability classes defined in the EMS-98, as most damage reports and vulnerability assessment are more easily compared using this scale (Table 4).

An analytic expression is defined for the operational implementation of the methodology; accordingly the mean damage grade μ_D is defined as a function of the macroseismic intensity I and depends on two parameters: the vulnerability index V_I and the ductility index Q [4]:

$$\mu_D = 2.5\left[1 + tanh\left(\frac{I + 6.25 \times V_I - 13.1}{Q}\right)\right], \quad (2)$$

where:

I – the macroseismic intensity,
V_I – the vulnerability index,
Q – the ductility index; it controls the slope of the curves and assumes different values to fit the data obtained through damage surveys; for residential buildings, the proposed value is 2.3 [4].

Based on this, damage probability matrices can be easily obtained by assuming that the damage probability follows a binomial or beta-equivalent probability distribution [4, 11]. According to [11], mean expected damage state is analogous to μ_D and, by considering the histogram of the damage grades occurred to the set of buildings, it is possible to define as representative parameter the mean damage grade μ_D [4]:

$$\mu_D = \sum_{k=0}^{5} p_k k \qquad 0 < \mu_D < 5 \quad (3)$$

where p_k is the probability of having damage of grade k, in the set of buildings.

Table 5 shows the most probable damage grade as a function of this average damage index that allows expressing seismic damage scenarios by using a single parameter. For easier analysis later in the paper, the damage grades are color coded according to Table 5.

Table 4 – Vulnerability index values for the vulnerability classes defined in EMS-98 [2]

Class	V_{Imin}	V_I^-	V_I^*	V_I^+	V_{Imax}	**Class**	V_{Imin}	V_I^-	V_I^*	V_I^+	V_{Imax}
A	0.78	0.86	0.90	0.94	1.02	**D**	0.30	0.38	0.42	0.46	0.54
B	0.62	0.70	0.74	0.78	0.86	**E**	0.14	0.22	0.26	0.30	0.38
C	0.46	0.54	0.58	0.62	0.70	**F**	-1.02	0.06	0.10	0.14	0.22

Table 5 - Damage states and mean damage index values [11]

Mean damage index intervals	Most probable damage state	EMS-98 Damage Grade
0-0.5	None	D0
0.5-1.5	Slight	D1 (Grade 1)
1.5-2.5	Moderate	D2 (Grade 2)
2.5-3.5	Substantial to heavy	D3 (Grade 3)
3.5-4.5	Very heavy	D4 (Grade 4)
4.5-5.0	Destruction	D5 (Grade 5)

6. Results

For all confined masonry buildings, we first calculated the average behavior modifier factor. Based on the statistics of 86 confined masonry buildings, the average behavior modifier factor was 0.12. The same procedure was applied for RC dual and RC SW buildings. For confined masonry buildings, using the summed behavior modifier factors for each building, we calculated the average behavior modifier factor. The same procedure was applied for RC dual and RC SW buildings. Considering only the 6 available RC SW buildings, the average modifier factor was 0.06. These buildings were in good state of preservation, mostly five storeys, regular in plane and height and standing alone. The behavior modifier for RC Dual buildings was obtained only on the basis of 4 buildings, of which 3 are similar. The average modifier factor was also 0.06.

For each building, the mean damage grade was calculated based on the V_I values. Each V_I value was calculated by summing all the behavior modifiers and regional modifier. Then the average V_I value is obtained. The vulnerability indices V_I are related to EMS-98 vulnerability class using Table 6 obtained by modifying the values from Milutinovic and Trendafiloski [8]. This relationship was presented in the work of Martinez-Cuevas and Gaspar-Escribano [16].

Thus, if we apply the modifiers, 36 confined masonry buildings (39.54 %), instead of vulnerability class D, are now vulnerability class C, and even 52 buildings (60.46%) become vulnerability class B. SW buildings and RC Dual systems belong to vulnerability class D and remain unchanged. It can be highlighted that the modifier factors can drastically influence the corresponding vulnerability class. It can also be concluded that the values of modifiers consequently have a high impact on the earthquake vulnerability assessment.

In Figure 5 we present the impact of the behavior and regional modifiers on the V_I values. The results are presented for the most represented type of structures: confined masonry (Figure 5). Four separate estimates are provided, resulting from the different approaches used to estimate the V_I values: The first one considers the typological V_I^* value (blue) for the M4 building typology, the second one considers the typological V_I^* value (red) for the corresponding building class according to EMS-98 (D), while the last two values consider all behavior modifiers – first (green) calculated for M4 typology and second one (violet) for the corresponding class according to EMS-98 (obtained by using Tables 6 and 4).

Table 6 – Relation between V_I and EMS98 classes [16]

V_I values	EMS-98 class
>0.82	A
0.66 – 0.82	B
0.5 – 0.66	C
0.34 – 0.5	D
0.18 – 0.34	E
<0.18	F

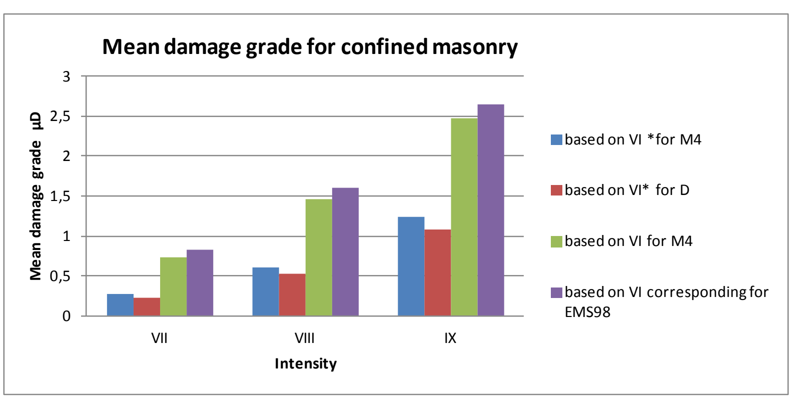


Fig 5. – Mean damage grade calculated for confined masonry buildings

For vulnerability class C, an average vulnerability index value of 0.6051 is obtained, while an average vulnerability index value of 0.6808 is obtained for 52 buildings having vulnerability class B.

Table 7 shows the corresponding mean damage grades expected in confined masonry and RC buildings for three levels of intensity (VI, VII and IX).

It can be seen that confined masonry has much lower seismic resistance when the mean damage grade is related to the probable damage grade. For earthquake intensity VIII, it can be seen that slight damage to moderate damage can be expected to be observed in these buildings. Also, for intensity IX even substantial to heavy damage can be expected. Results of calculation for confined masonry is further presented for two classes belonging now to vulnerability classes B and C, which is presented in Table 8, to get insight in differences between average mean damage grade according to Milutinovic and Trendafiloski [8] and with obtained values for EMS-98 [2].

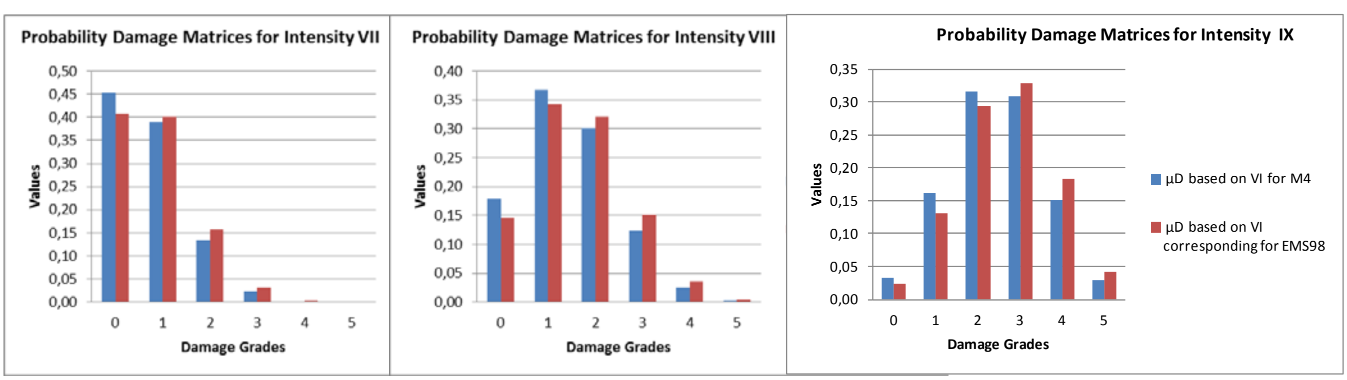
Starting from these mean damage grades, damage probability matrices are obtained, which is presented in Fig. 6.

Table 7 – Average values of mean damage grades for three levels of intensity

Intensity	Average μ_D for confined masonry		Average μ_D for reinforced concrete	
	M4	EMS-98	RC2 and RC3	EMS-98 (D)
VII	0.733	0.822	0.270	0.232
VIII	1.454	1.597	0.598	0.521
IX	2.472	2.641	1.225	1.086

Table 8 – Average values of mean damage grades for three levels of intensity for obtained vulnerability classes

Intensity	Confined masonry		Reinforced concrete
	For obtained vulnerability class B	For obtained vulnerability class C	Vulnerability class D
VII	0.846	0.592	0.232
VIII	1.633	1.211	0.521
IX	2.679	2.159	1.086



a) VII b) VIII c) IX

Fig. 6 – Damage probability matrices for confined masonry for three level of intensity: a) VII, b) VIII and c) IX.

A significant increase in the modifier implies a general shift of buildings toward higher vulnerability classes. The analysis is then focused in the damage distribution of these vulnerability classes. Therefore, in Tables 9 and 10, the results are presented in the form of quantities and vulnerability classes according to EMS-98, where the mean damage grades are calculated according to the Milutinovic and Trendafiloski [8]. The quantities are determined using ranges as suggested in Grunthal et al. [2]: few, many and most are defined as three contiguous ranges of percentages (e.g. 0-20%, 20-60%, 60-100%).

7. Conclusion

This paper processes 100 building from Osijek's area. To evaluate the vulnerability evaluation for each building, we followed the vulnerability index method as the initial vulnerability assessment approach in this study. We also used the EMS-98 vulnerability approach to aid in the interpretation of results. Therefore, structural typology, age and other characteristics (such as regularity, position etc.) of the buildings were considered. For each building, the mean damage grade was calculated based on vulnerability indices, which were obtained by using typological values for every structural system and adding regional and behavior modifiers. Since there are no available data of damaged buildings under earthquake loading in our country, we propose behavior modifiers based on values suggested by earlier works and on judgement based on available project documentation of the considered buildings. Since most damage reports and vulnerability assessment are more easily compared using EMS-98, we translated the V_I estimates obtained into the vulnerability classes defined by EMS-98. It can be concluded that the regional and behavior vulnerability modifiers affect the average value V_I so much that the vulnerability class is increased by one or two classes.

Table 9 - Percentage of buildings with different damage grades for three intensity level for class B

Intensity		VII		VIII		IX	
Class	**Damage grade**	% of buildings	Quantity EMS-98	% of buildings	Quantity EMS98	% of buildings	Quantity EMS-98
B	1	40.30%	Many	33.58%	Many	12.43%	A few
	2	16.41%	A few	32.57%	Many	28.71%	Many
	3	3.34%	A few	15.80%	A few	33.15%	Many
	4	0.34%	None	3.83%	A few	19.14%	Many
	5	0.01%	None	0.37%	None	4.42%	A few

Table 10 - Percentage of buildings with different damage grades for three intensity level for class C

Intensity		VII		VIII		IX	
Class	**Damage grade**	% of buildings	Quantity EMS-98	% of buildings	Quantity EMS98	% of buildings	Quantity EMS-98
C	1	35.76%	Many	39.93%	Many	22.51%	Many
	2	9.61%	A few	25.53%	Many	34.21%	Many
	3	1.29%	A few	8.16%	A few	25.98%	Many
	4	0.09%	None	1.30%	A few	9.87%	A few
	5	0.00%	None	0.08%	None	1.50%	A few

8. Acknowledgements

We thank the National/State Archives in Osijek in aiding and providing the project documentations for selected buildings.

9. References

[1] Herak M (2012): Hrvatska karta potresne opasnosti, *Zbornik radova s IV. Konferencije Hrvatske platforme za smanjenje rizika od katastrofa*, Zagreb, pp. 4-12 (in Croatian).

[2] Grünthal G. (ed.), Musson R M W, Schwarz J, Stucchi M (1998): European Macroseismic Scale 1998. *Cahiers du Centre Européen de Géodynamique et de Séismologie*, Volume 15, Luxembourg.

[3] Bernardini A (2000): The vulnerability of buildings—evaluation on the national scale of the seismic vulnerability of ordinary buildings. CNR-GNDT, Rome.

[4] Giovinazzi S (2005): The Vulnerability Assessment and the Damage Scenario in Seismic Risk Analysis. PhD Thesis, Department of Civil Engineering of the Technical University Carolo-Wilhelmina at Braunschweig and the Faculty of Engineering Department of Civil Engineering of the University of Florence.

[5] Schwarz J, Abrahamczyk L, Leipold M, Wenk T (2015): Vulnerability assessment and damage description for R.C. frame structures following the EMS-98 principles. *Bulletin of Earthquake Engineering,* **13**, 1141–1159.

[6] Benedetti D, Petrini V (1984): On seismic vulnerability of masonry buildings: proposal of an evaluation procedure. *The industry of constructions* 18:66–78.

[7] Benedetti D, Benzoni G, Parisi MA (1988): Seismic vulnerability and risk evaluation for old urban nuclei. *Earthquake Engineering and Structural Dynnamics* 16:183–201.

[8] Milutinovic ZV, Trendafiloski GS (2003): RISK-UE, An advanced approach to earthquake risk scenarios with applications to different European towns. *Report to WP4: Vulnerability of current buildings*, 109 p.

[9] Coburn A, Spence R (1992): *Earthquake Protection*. John Wiley & Sons, Chichester.

[10] Giovinazzi S, Lagomarsino S (2004): A Macroseismic Method for the Vulnerability Assessment of Buildings. *13th World Conference on Earthquake Engineering*, Vancouver, Canada, Paper No. 896.

[11] Lantada N, Irizarry J, Barbat AH, Roca A, Susagna T, Pujada LG (2010): Seismic hazard and risk scenarios for Barcelona, Spain, using the Risk-UE Vulnerability index method. *Bulletin of Earthquake Engineering,* 8:201–229.

[12] Oliveira CS, Mendes Victor LA (1984): Prediction of seismic impact in a metropolitan area based on hazard analysis and microzonation: methodology for the town of Lisbon. *8th World Conference on Earthquake Engineering*, El Cerrito, California, Vol. VII, pp. 639-646.

[13] Feriche M, Vidal F, Jimenez C, Navarro M (2008): A straightforward method applicable to Earthquake Damage Scenarios and Early Loss Assessment in urban areas of Southern Spain. *31st General Assembly of the European Seismological Commission ESC*, Hersonissos, Crete, Greece.

[14] Tsereteli N, Arabidze V, Varazanashvili O, Gugeshashvili T, Mukhadze T, Gventcadze A (2014): *Vulnerability Analysis and GIS Based Seismic Risk Assessment Georgia Case*, in the book: Teodoresco H-N, Kirschenbaum A, Cojocaru S, Bruderlein C,Springer (eds) Improving Disaster Resilience and Mitigation – IT Means and Tools, NATO Science for Peace and Security Series C: Environmental Security DOI 10.1007/978-94-017—9136-6_20, Springer Science+Business Media Dordrecht 2014

[15] Barbat AH, Carreño ML, Pujades LG, Lantada N, Cardona OD, Marulanda MC (2001): Seismic vulnerability and risk evaluation methods for urban areas. A review with application to a pilot area. *Structure and Infrastructure Engineering*, **6** (1-2), 17-38.

[16] Martinez-Cuevas S, Gaspar-Escribano JM (2016): Reassessment of intensity estimates from vulnerability and damage distributions: the 2011 Lorca earthquake. *Bulletin of Earthquake Engineering*. DOI 10.1007/s10518-016-9913-8.