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SEISMIC VULNERABILITY ASSESSMENT OF BUILDINGS IN AN URBAN AREA: A CASE STUDY OF SELECTED CITY BLOCKS IN OSIJEK

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1. Introduction

- Eastern part od Croatia is characterized by the relatively rare occurrence of strong earthquakes [1].
- Almost 37% of the territory faces a high risk of earthquakes of VIII and IX degree of intensity according to the Mercalli-Cancani-Sieberg (MCS) scale [2].
- According to the MCS, the risk of a VII degree of earthquake intensity exists on more than 55% of the territory's surface.

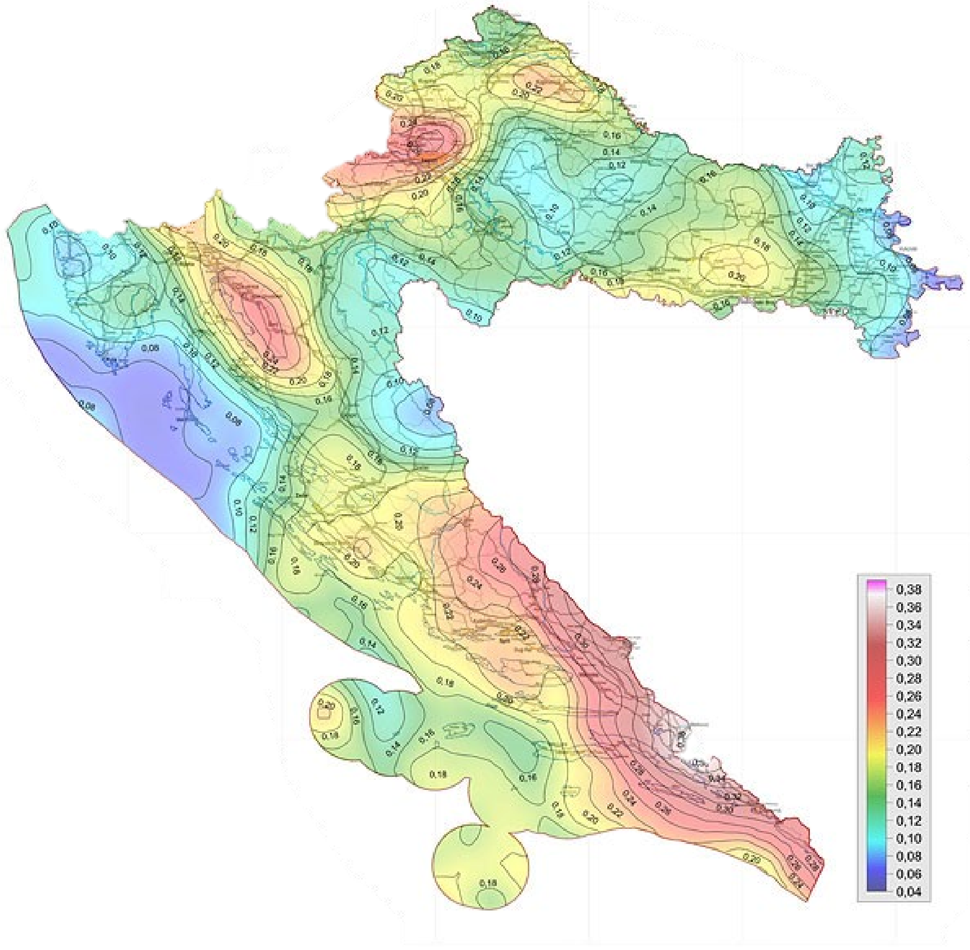

Figure 1. Map of seismic areas of the Republic of Croatia [3]

1. Introduction

- The first step in protecting the city from earthquakes and disasters is forming a theoretical prediction of consequences – structural damage and socioeconomic losses.
- Enhancing earthquake protection involves constructing new buildings with high earthquake resistance and diligently monitoring and maintaining existing structures.

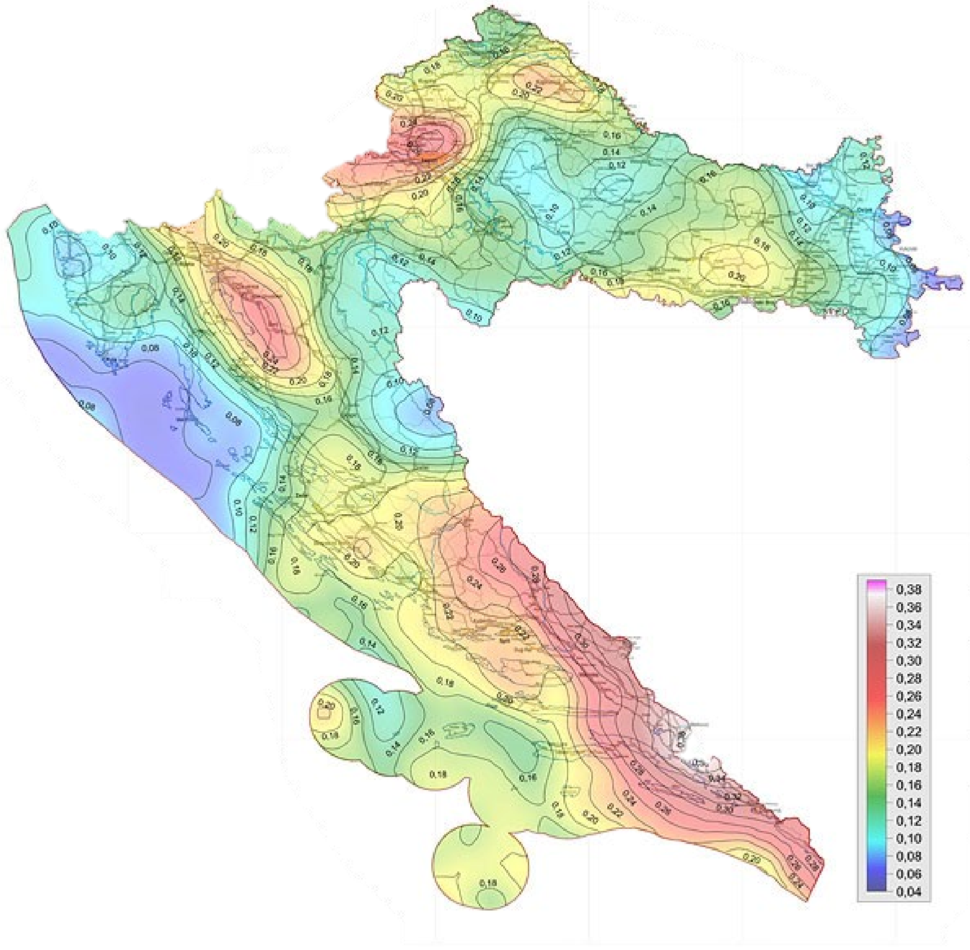

Figure 1. Map of seismic areas of the Republic of Croatia [3]

1. Introduction

- To assess seismic risk in an urban area, it is essential to:

a. define seismic hazard

b. create a building database based on various factors

c. evaluate fragility and vulnerability using suitable methods

- These measures aim to estimate the potential risk to residents and property in the event of earthquake ground motion [4].

2. Buildings database

- A database of the observed buildings was created using tehnical documentation, field visits and data from the State Geodetic Administration of the Republic of Croatia [5].
- Building taxonomy is crucial for seismic risk assessment studies – it classifies buildings based on set of attributes that can impact the probability and severity od earthquake-induced damage [6].
- In Croatia, the Long-Term Strategy for Encouraging Investments in the Restoration of the National Building Stock offered an overview of the country's building stock using census data and expert estimates [7].

2. Buildings database

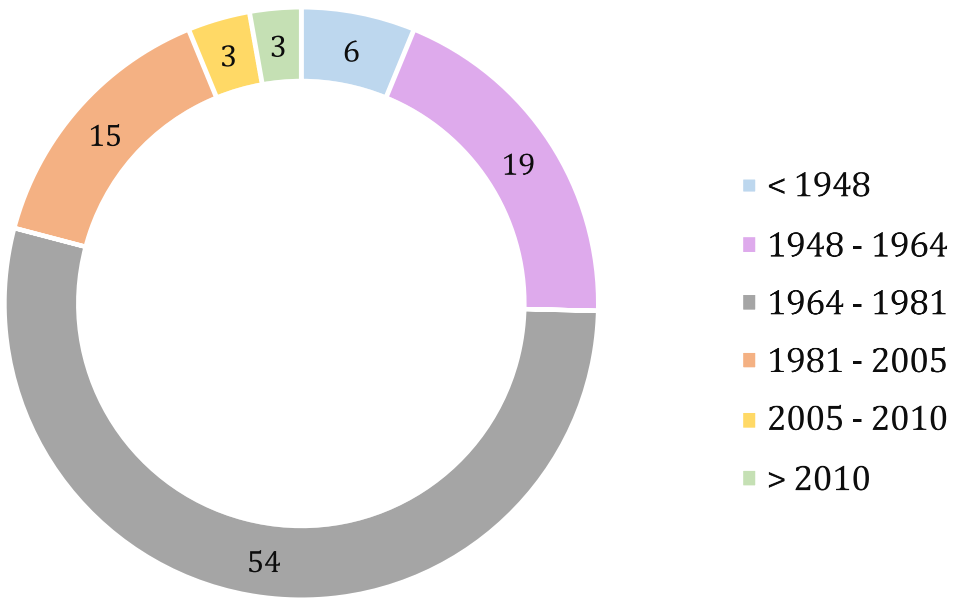

Figure 2. Period of the built buildings (%)

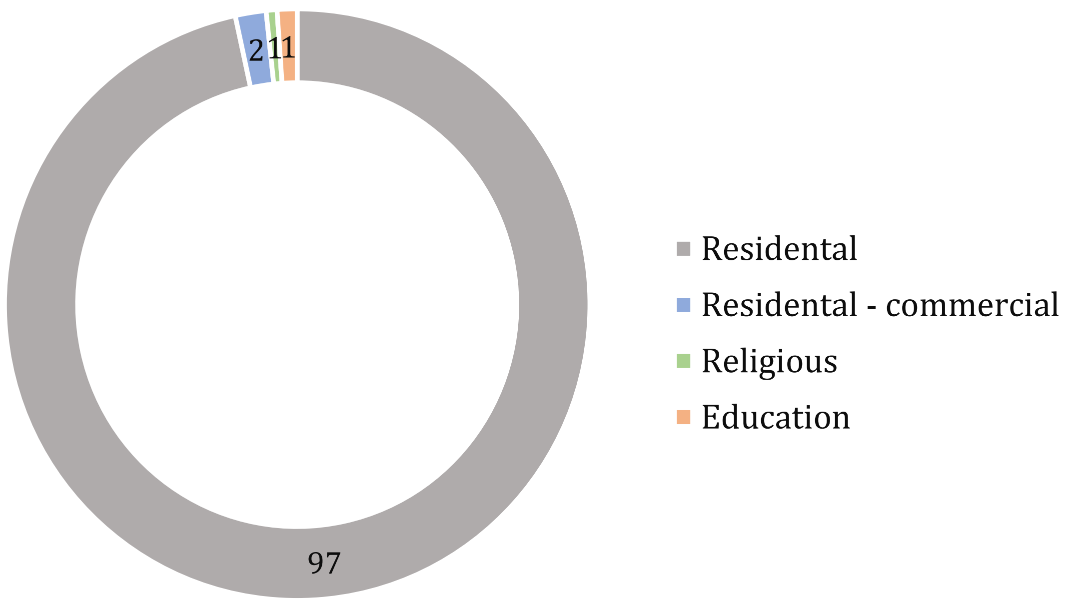

Figure 3. Purpose of the buildings (%)

2. Buildings database

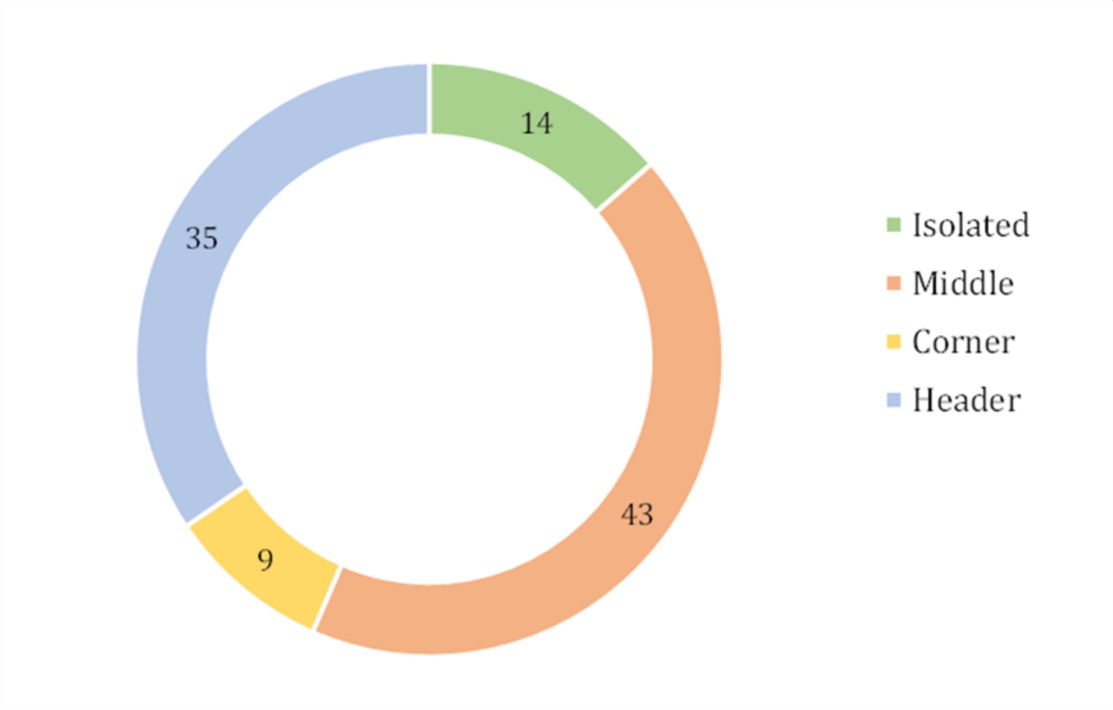

Figure 4. Position of the building within the block (%)

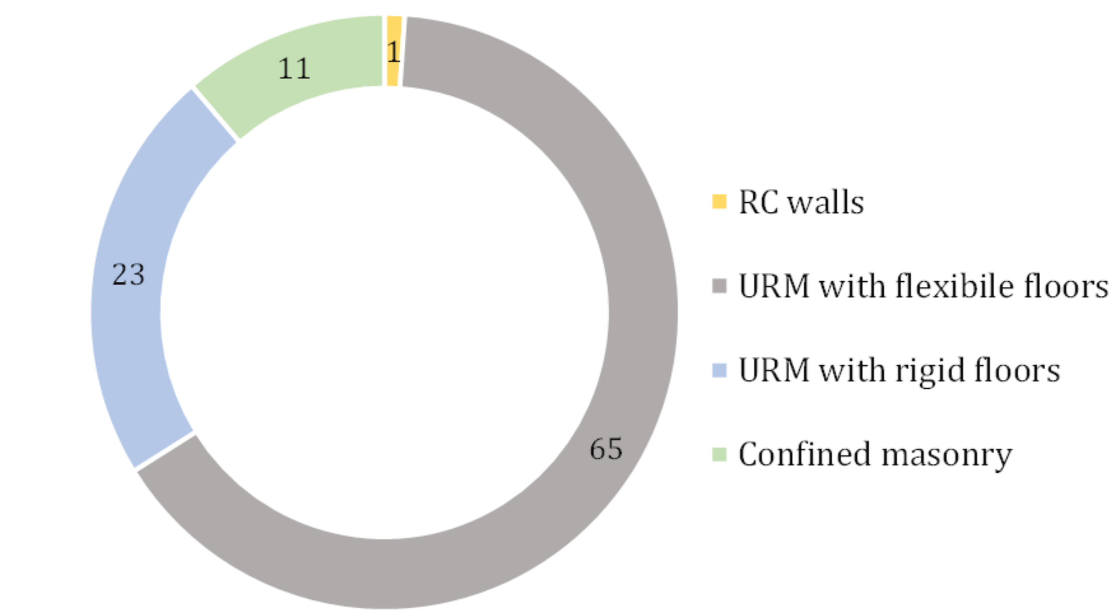

Figure 5. Distribution of structural systems (%)

2. Buildings database

Figure 5. Structural typologies in the observed street: (a) M2, (b) M3.1, (c) M3.4

2. Buildings database

Figure 6. Structural typologies in the observed street: (d) M4, (e) RC2

2. Buildings database

Figure 7. State of preservation (%)

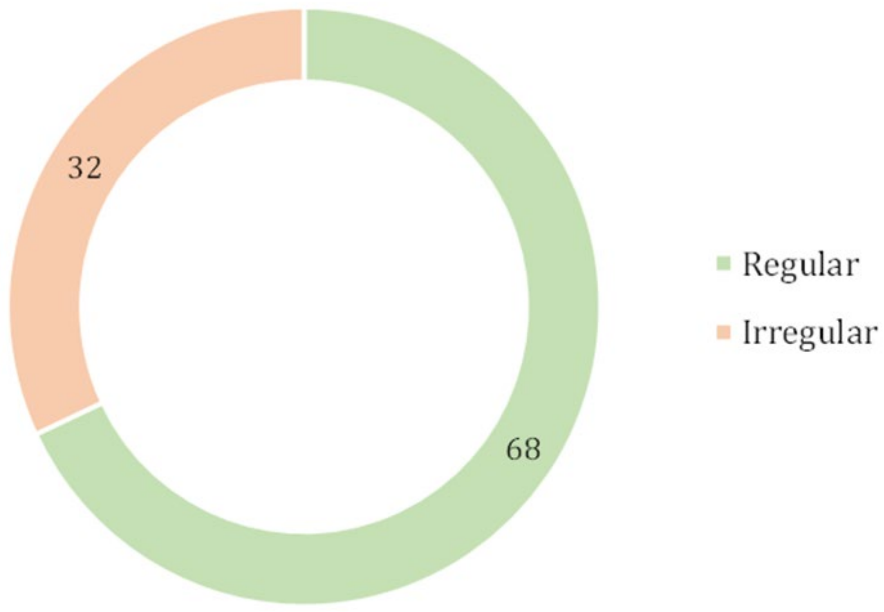

Figure 8. Regularity in plan (%)

3. Assessment of earthquake vulnerability through the macroseismic method

- Main goal of the macroseismic method is to create vulnerability model that shows the probability of damage and the probability distribution for a given earthquake intensity [8].
- Earthquake vulerability is determined based on the vulnerability index, V and the ductility index, Q.
- Earthquake hazard is expressed by macroseismic intensity according to the European macroseismic scale EMS-98 [9], which is evaluated concerning the ground motions.

3. Assessment of earthquake vulnerability through the macroseismic method

- **The mean damage grade, μ_d** is expressed depending on macroseismic intensity, I and vulnerability index, V_I through the following function [10]:

$$\mu_d = 2,5\left[1 + \tanh\left(\frac{I + 6,25 \cdot V_I - 13,1}{Q}\right)\right] \quad (1)$$

where:

I	is earthquake hazard defined in terms of macroseismic intensity
V	is the vulnerability index
Q	is the ductility factor that describes the ductility of a certain structural typology.

3. Assessment of earthquake vulnerability through the macroseismic method

Table 1. Vulnerability index values for different vulnerability classes

Intervals of mean damage grade	The most likely level of damage of certain limit states	Vulnerability classes, according to EMS-98
0.0 – 0.5	none	D0
0.5 – 1.5	slight	D1 (Grade 1)
1.5 – 2.5	moderate	D2 (Grade 2)
2.5 – 3.5	significantly to severely	D3 (Grade 3)
3.5 – 4.5	very severe	D4 (Grade 4)
4.5 – 5.0	collapse	D5 (Grade 5)

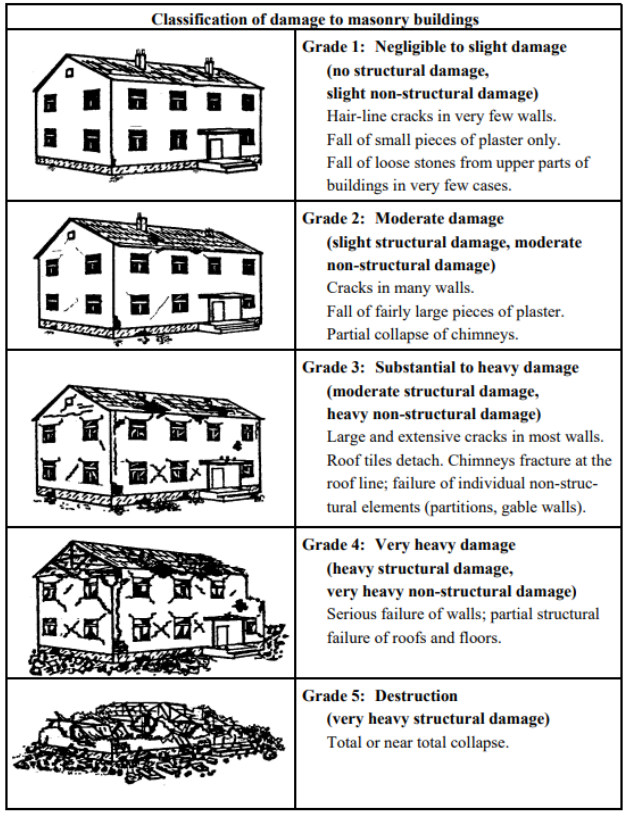

Figure 9. Classification of damage to masonry buildings

3. Assessment of earthquake vulnerability through the macroseismic method

- According to EMS-98, vulnerability classes divided into six classes, based on their vulnerability index.

Table 2. Vulnerability classes according to EMS-98

Vulnerability classes	A	B	C	D	E	F
V	> 0.82	0.66 – 0.82	0.50 – 0.66	0.34 – 0.50	0.18 – 0.34	< 0.18

3. Assessment of earthquake vulnerability through the macroseismic method

- After calculating the mean damage grade, it is necessary to obtain the probability p_{k} of the existence of each degree of damage D_{k} (k = 0, … ,5) for a certain mean damage grade, μ_{d} determined using the probability distributions of a discrete variable of binomial distribution:

$$p_{\mathrm{k}} = \frac{5!}{k! \cdot (5-k)!} \cdot \left[\frac{\mu_{\mathrm{d}}}{5}\right]^{k} \cdot \left[1 - \frac{\mu_{\mathrm{d}}}{5}\right]^{5-k} \tag{2}$$

3. Assessment of earthquake vulnerability through the macroseismic method

- **The vulnerability index *V*** is determined according to (3) to take into account the fact that the seismic behavior of the building does not depend only on the behavior of the structural system but also includes other factors:

$$V = V_0 + \Delta V_{\mathrm{r}} + \Delta V_{\mathrm{m}} \tag{3}$$

where:

V_0 is the most likely value of the typological vulnerability index of a building type,
ΔV_{r} is the regional vulnerability factor,
ΔV_{m} is the behavior modifier.

3. Assessment of earthquake vulnerability through the macroseismic method

- Values of **typological vulnerability index, V_0** were adopted according to Milutinović and Trendafiloski [11], depending on the type of the structure.
- Value of the **regional factor, ΔV_r** in the database used to assess the vulnerability of buildings is 0.
- The **behaviour modifier, ΔV_m** is calculated according to (4) which can increase or decrease vulnerability index.

$$\Delta V_{\mathrm{m}} = \sum_{k} \Delta V_{\mathrm{m,k}} \tag{4}$$

where:

ΔV_{m} is the behavior modifier (Milutinović and Trendafiloski [11])
$\Delta V_{\mathrm{m,k}}$ is the modifier for certain building characteristics.

4. Results

- There is significant presence of vulnerability class B – which justifies that the street has the largest number of buildings with structure typology M3.1, whose most likely damage class is class B.
- A certain part of masonry buildings with flexible floor structures as well as masonry buildings with adobe bricks have vulnerability class A – due to their age, bad maintaince or other characteristics that affects earthquake resistance.

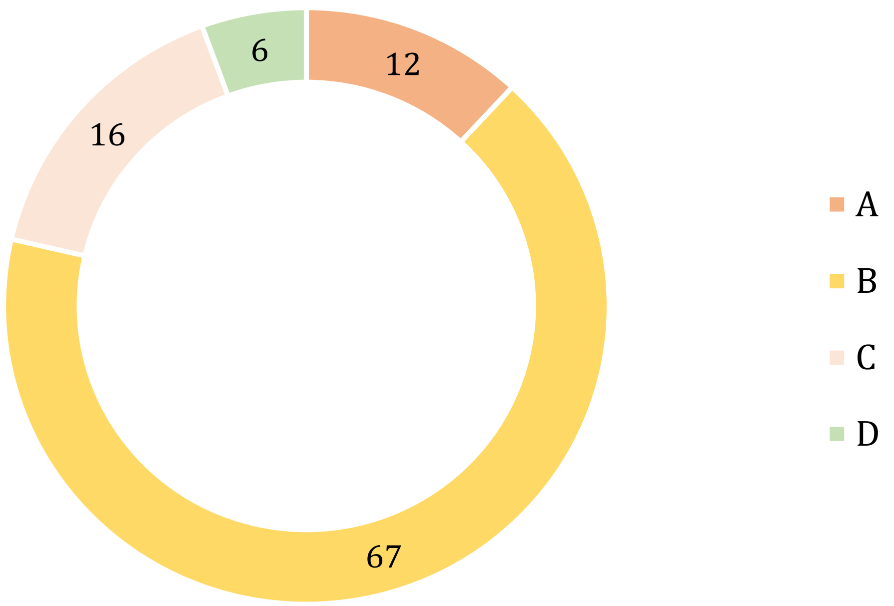

Figure 10. Representation of a particular vulnerability class in Crkvena Street, according to EMS-98 (%)

4. Results

- Based on the mean damage grade values and the binomial distribution, damage probability matrices were calculated for damage degrees from 0 to 5 according to the EMS-98 damage classification for VII, VIII, and IX degree of earthquake intensity.

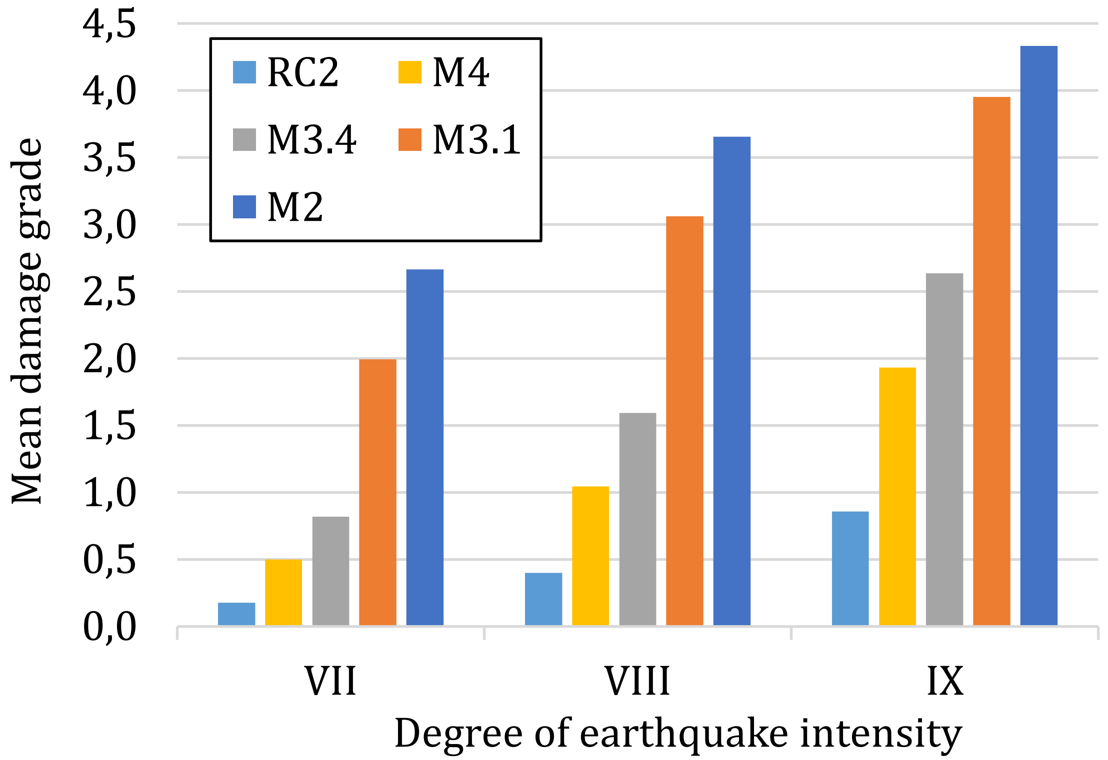

Figure 11. Comparison of the mean damage grade depending on the degree of earthquake intensity for different typologies of buildings

4. Results

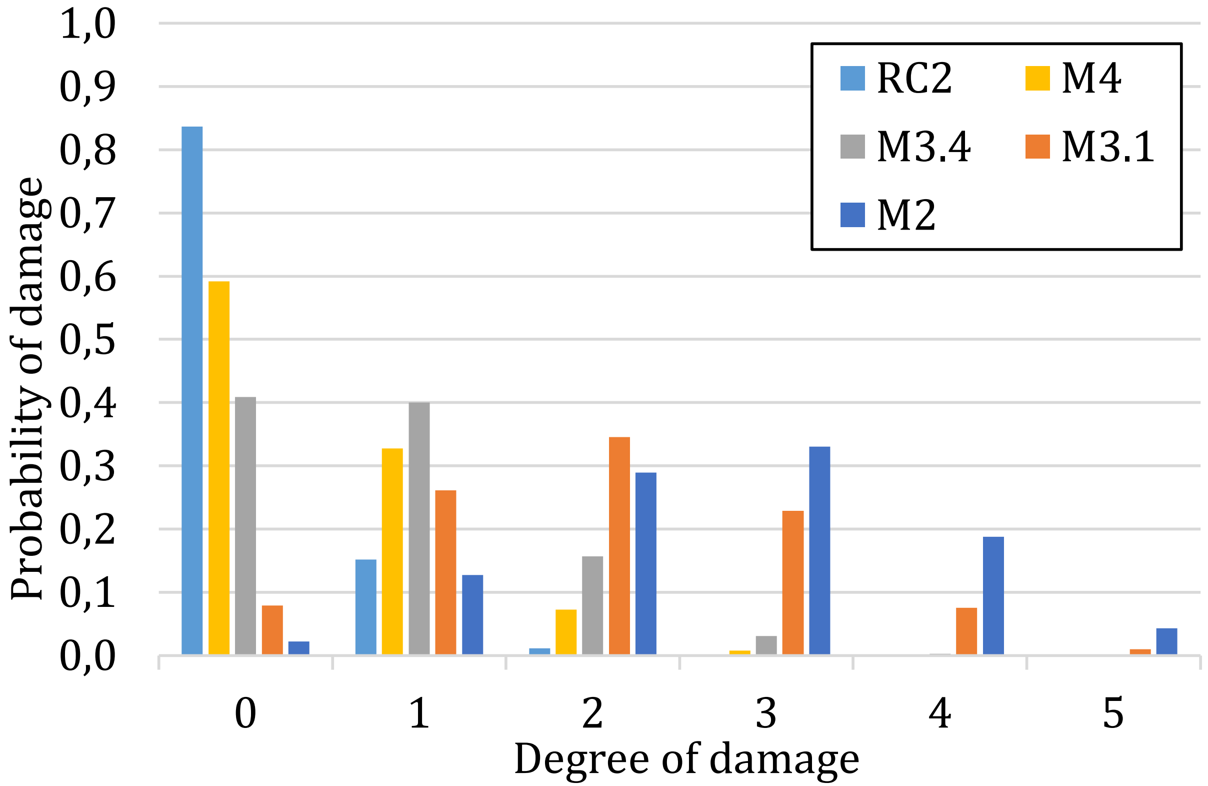

Figure 12. Graphical comparison of damage probability matrices for earthquake intensity degree VII

4. Results

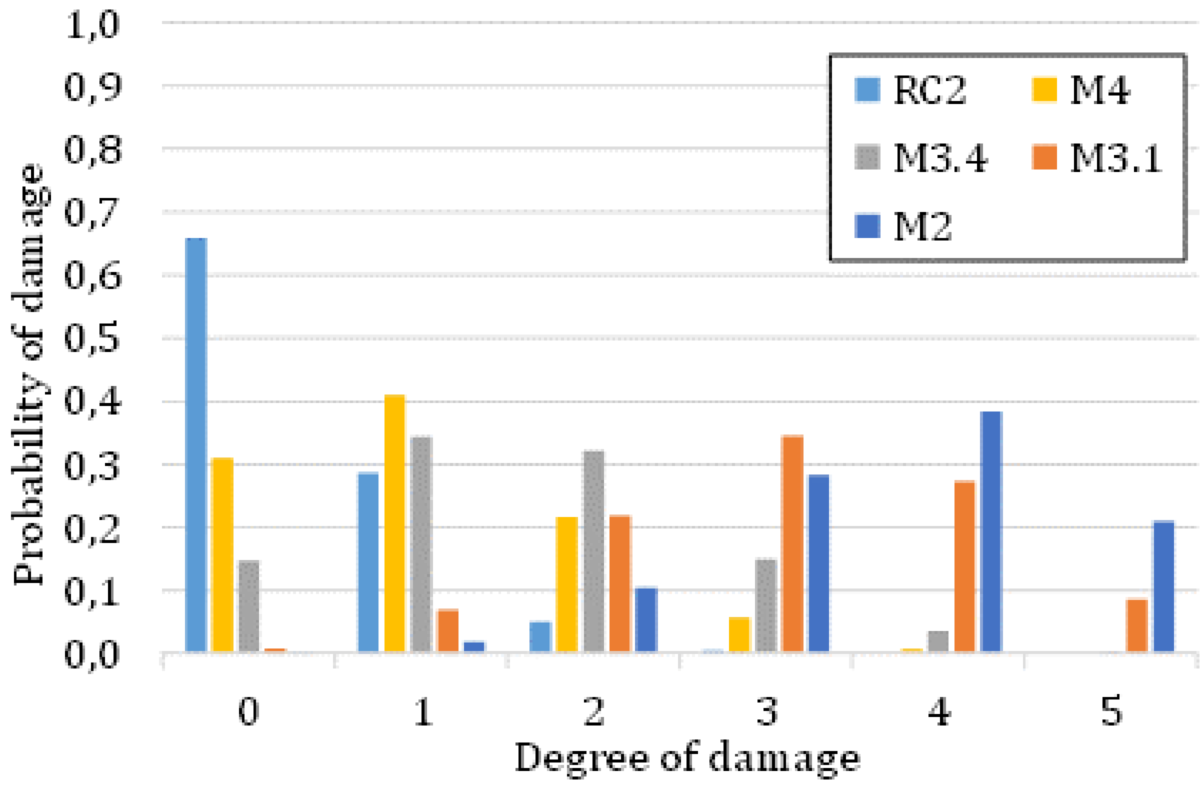

Figure 12. Graphical comparison of damage probability matrices for earthquake intensity degree VIII

4. Results

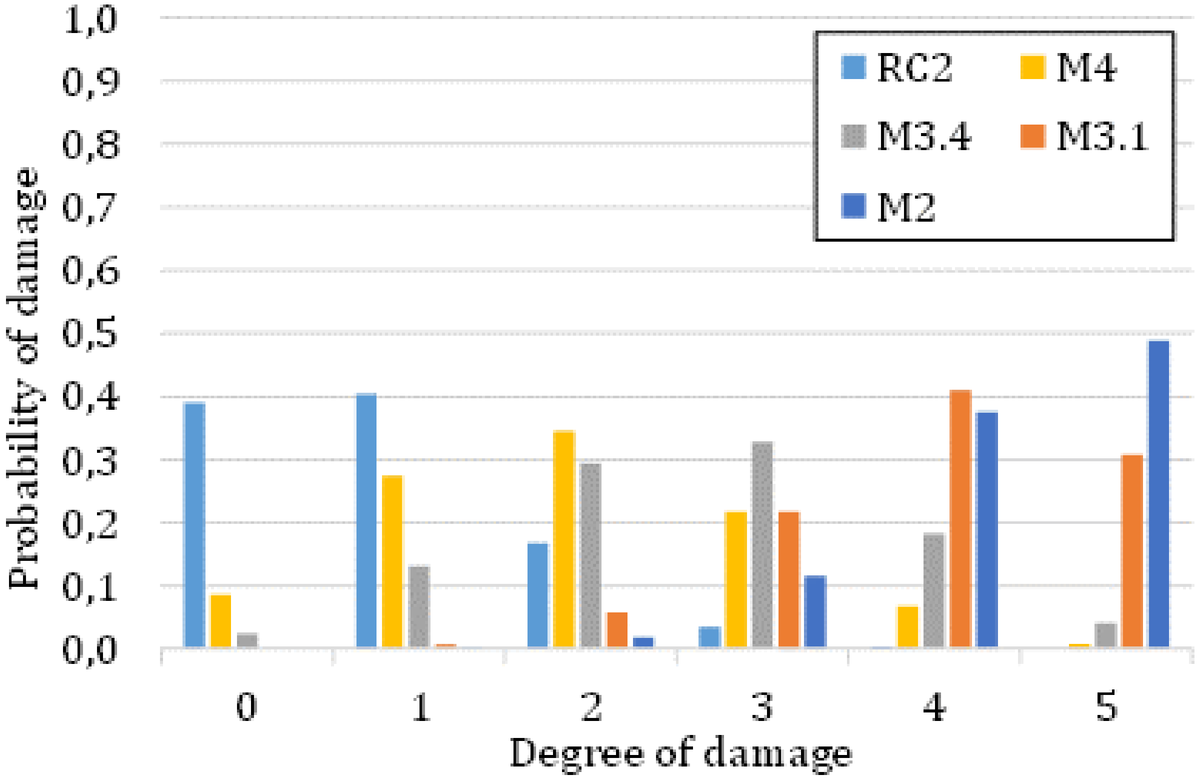

Figure 13. Graphical comparison of damage probability matrices for earthquake intensity degree IX

5. References

1. Kuk, K., Ivančić, I., Sović, I., Mustać, M., Fiket, T., Šariri, K.: Priručnik za integraciju seizmoloških podataka.
2. Procjena ugroženosti Republike Hrvatske od prirodnih i tehničko tehnoloških katastrofa i velikih nesreća, Zagreb (2009)
3. Herak, M., Allergretti, I., Herak, D., Ivančić, I., Kuk, V., Marić, K.: Karte potresnih područja Republike Hrvatske. Availible at: http://seizkarta.gfz.hr/hazmap/karta.php
4. Ademović, N., Hadzima-Nyarko, M., Zagora, N.: Seismic vulnerability assessment of masonry buildings in Banja Luka and Sarajevo (Bosnia and Herzegovina) using the macroseismic model. Bulletin of Earthquake Engineering. 18, 3897–3933 (2020). https://doi.org/10.1007/s10518-020-00846-8

6. References

5. Državna geodetska uprava, https://dgu.gov.hr/
6. Blagojević, N., Brzev, S., Petrović, M., Borozan, J., Bulajić, B., Marinković, M., Hadzima-Nyarko, M., Koković, V., Stojadinović, B.: Residential building stock in Serbia: classification and vulnerability for seismic risk studies. Bulletin of Earthquake Engineering. 21, 4315–4383 (2023). https://doi.org/10.1007/s10518-023-01676-0
7. Pavić, G., Hadzima-Nyarko, M., Bulajić, B., Jurković, Ž.: Development of seismic vulnerability and exposure models-A case study of Croatia. Sustainability (Switzerland). 12, (2020). https://doi.org/10.3390/su12030973
8. Hadzima-Nyarko, M., Nikić, D., Morić, D.: Potresno inženjerstvo – procjena oštetljivosti zgrada. Sveučilište Josipa Jurja Strossmayera Osijek, Osijek (2018)

6. References

9. Grünthal, Gottfried., European Seismological Commission. Working Group “Macroseismic Scales.”: European macroseismic scale 1998 : EMS-98. European Seismological Commission, Subcommission on Engineering Seismology, Working Group Macroseismic scales (1998)
10. Lagomarsino, S., Giovinazzi, S.: Macroseismic and mechanical models for the vulnerability and damage assessment of current buildings. Bulletin of Earthquake Engineering. 4, 415–443 (2006). https://doi.org/10.1007/s10518-006-9024-z
11. Milutinovic, Z. V, Trendafiloski, G.S.: RISK-UE An advanced approach to earthquake risk scenarios with applications to different European towns WP4: Vulnerability of current buildings. (2003)

Thank you for your attention!