Seismic Vulnerability Assessment of Rural Areas: Case Study of the Vrutok Village and Recane Village in Gostivar, North Macedonia, Using Vulnerability Index Method

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Abstract

Applying methodologies that enable faster evaluation of larger numbers of buildings are frequently applied approaches for seismic vulnerability assessment in larger urban areas. The same methods can also be useful in examining large numbers of existing buildings in rural areas. Considering the high seismic vulnerability of masonry buildings and the fact that there is large number of masonry buildings in rural areas, seismic risk assessment in these areas is particularly important. Masonry buildings in rural areas of the Republic of North Macedonia were mostly built in the late nineteenth and early twentieth century's or earlier. Where it is clearly seen that these buildings were built before the existence of seismic design regulations. The aim of the research is to examine the vulnerability of existing masonry buildings in the selected areas, in order to analyze the seismic risk. In the research, two villages were selected for analysis. In the article, the vulnerability index method was applied to evaluate the vulnerability of existing masonry buildings in the village Vrutok and village Recane in Gostivar, North Macedonia. As part of research, 49 buildings were evaluated, where 26 buildings are in the village Vrutok and 23 buildings in the village Recane.

Keywords: *Masonry buildings, Seismic risk, Vulnerability*

1. Introduction

There are old masonry buildings in North Macedonia that were built before seismic design regulations. Which in the event of an earthquake can experience major damage. The rehabilitation of the facilities requires large financial resources that cannot be done all at once. Therefore, systematic planning for vulnerability assessment is needed to identify buildings or areas at higher risk (Nikolic et all., 2021).

Assessment of the vulnerability of buildings can be defined as their susceptibility to damage at certain earthquake intensity. The assessment aims to obtain the probability that a given class of buildings will exceed a certain damage level for a given earthquake scenario. Many seismic vulnerability assessments methods have been proposed in recent years. Seismic vulnerability assessment methods can be divided into two categories: empirical methods based on damage observation and analytical methods based on structural performance evaluation through analytical models (Lumantarna et all., 2014).

Seismic vulnerability assessment methods are used from individual buildings to large urban areas. To choose the appropriate method, the purpose of the research, the scope of work, the approach to obtaining information, available resources and computational effort should be considered (Vicente et all., 2011, pp.1067-1096). In the article two villages in the city of Gostivar were analyzed, and because of field research, 49 existing masonry buildings were identified. The reason for choosing these villages is that there are many existing masonry buildings in both villages. These buildings were built before the current seismic design regulations, and these buildings are used by many people today. To calculate the vulnerability of buildings, the vulnerability index, which is a hybrid method, was chosen. After calculating the vulnerability index, the average damage level of the buildings was calculated for four different scenarios of macro seismic intensity to evaluate possible damages.

2. Method

The seismic vulnerability index methodology, considered as a hybrid technique in literature, is based on the calculation of a vulnerability index resulting from the contribution of 14 parameters determined for each building examined. Table 1 presents all the parameters with classes (C_{vi}) and the weight factors proposed by Vicente and Ferreira (Vicente, 2008) (Ferreira et all., 2017).

$$I_{vf}^{*} = \sum_{i=1}^{14} C_{vi} \cdot P_{vi} \quad (1)$$

In Table 1, four vulnerability classes (C_{vi}), (A, B, C, D) are assigned to each parameter. Then, each parameter is associated with a weighting factor, which varies from 0.5 to 2.5. Depending on the contribution of the parameter to the building, less contribution is determined as lower value and more contribution as higher value. The vulnerability index I^{*}_{vf} can have values in the range from 0 to 675. For its ease of use, the value is normalized fron 0 to 100. The lower the value of I^{*}_{vf} (normalized vulnerability index), the lower the seismic vulnerability of the considered building.

14 parameters are categorized into four groups (Vicente, 2008). The first group of parameters refers to the construction system of the building, such as type of material, quality of construction, soil conditions, number of floors, etc. A second group of parameters is considered for irregularities and interaction with other buildings. Irregularities in base and height, arrangement of openings and position of a building in a plot in relation to neighboring buildings. This group of parameters refers to interfloor construction and roof. While the fourth group of parameters refers to non-constructive elements and the condition of the building (Speranza, 2003), (Ferreira, 2010), (Vicente et all., 2011, pp.1067-1096), (Ferreira et all., 2014, pp. 541-561).

For the operational application of the methodology, an analytical expression has been proposed that connects the hazard with a mean damage grade ($0<\mu_D<5$) of the damage distribution (discrete beta distribution) in relation to the value of seismic vulnerability.

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

$$0 \le \mu_D \le 5, \quad (2)$$

Table1. Parameters for calculating the vulnerability index (Vicente et all., 2011)

Parameters	CLASS () A B C D	Weight factor	
		Vicente, 2008	Ferreira, 2017
Group 1. Structural building system			
P1.Type of resisting system	0 5 20 50	0.75	2.50
P2.Quality of resisting system	0 5 20 50	1.00	2.50
P3.Conventional strength	0 5 20 50	1.50	1.00
P4.Maximum distance between walls	0 5 20 50	0.50	0.50
P5.Number of floors	0 5 20 50	1.50	0.50
P6.Location and soil conditions	0 5 20 50	0.75	0.50
Group 2. Irregularities and interaction			
P7. Aggregate position and interaction	0 5 20 50	1.50	1.50
P8. Plan configuration	0 5 20 50	0.75	0.50
P9. Irregularity in elevation	0 5 20 50	0.75	0.50
P10. Wall façade openings and alignments	0 5 20 50	0.50	0.50
Group 3. Floor slabs and roofs			
P11.Horizontal diaphragms	0 5 20 50	0.75	0.75
P12. Roofing system	0 5 20 50	2.00	0.50
Group 4. Conservation state and other elements			
P13. Conservation state	0 5 20 50	1.00	1.00
P14. Non-structural elements	0 5 20 50	0.75	0.75

The value of the intermediate damage level, depends on three values, the vulnerability index (V), the macro seismic intensity (I), and the ductility factor (Q).

3. Seismic Vulnerability of the Village Vrutok and the Village of Recane

The villages chosen for the analysis of the vulnerability of the existing masonry building are the villages of Vrutok (figure 1) and the villages of Recane (figure 2). The village of Vrutok is in the southwestern part of the city of Gostivar with a population of 640 inhabitants (according to the 2021 census).

Figure 1. View of Vrutok village (URL 1)

The village of Recane is in the southwestern part of the city of Gostivar with a population of 683 inhabitants (according to the 2021 census) (URL2). In both villages there are masonry buildings built before the seismic design regulations, that is, before 1964.

Figure 2. View of Recane village (URL 3)

In the village Vrutok, 26 existing masonry buildings have been identified (figure 3 – a; b), all of which are single-family houses. %15 of the buildings is with one floor, while %85 of the buildings is with two floors. %61.5 of the buildings are built of rubble stone or adobe, %38.5 of the buildings is built of simple stone or brick.

a) b)

Figure 3. a); b); Existing masonry buildings in Vrutok village (by author)

In the village of Recane, 23 existing masonry buildings have been identified (figure 4 – a, b), which are intended as single-family houses. %17.3 of the buildings are one-story while %82.7 of the buildings are two-story. %78.2 of the buildings are built of rubble stone or adobe, %21.8 of the buildings is built of simple stone or brick.

a) b)

Figure 4.a); b); Existing masonry buildings in Recane village (by author)

3.1. Results of the Seismic Vulnerability of the Village of Vrutok and the Village of Recane

In the study, field studies were carried out to determine the masonry buildings in both villages. The data collected from field research was done by filling in a form where the information needed for the calculation of the vulnerability index I^*_{vf}, was collected, in relation to the data for 14 parameters shown in table 1. The assessment of seismic vulnerability is made through the calculation of the vulnerability index I^*_{vf}, which is calculated by equation (2). The vulnerability index I^*_{vf} is normalized feom 0 to 100. In the calculation of the vulnerability index the weighting factors provided by Vicente and Ferreira were used. In figure 5 and figure 6 is show percentage representation of buildings according to normalized vulnerability index I^*_{vf}. Spatial distribution of normalized vulnerability index I^*_{vf} is shown in figures 7 and 8.

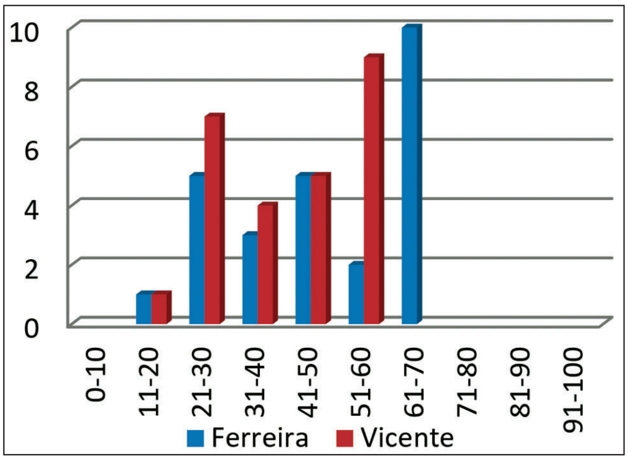


Figure 5. Percentage representation of buildings according I_{vf}-Vrutok (by author)

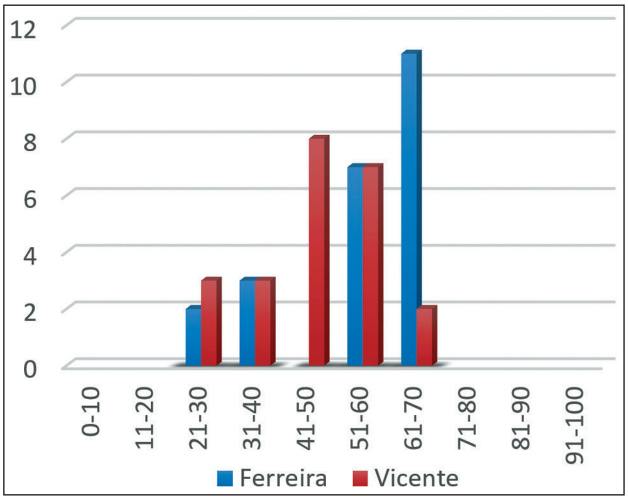
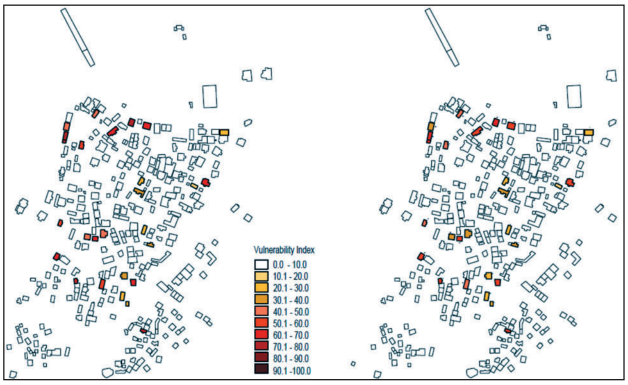
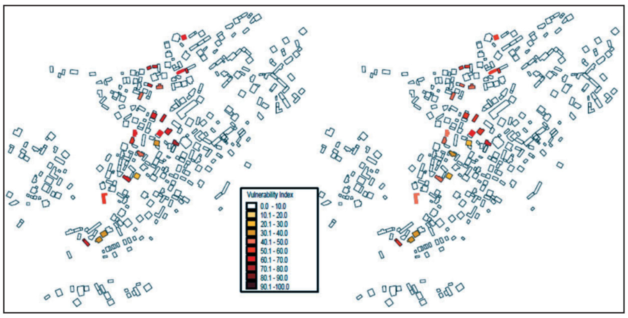


Figure 6. Percentage representation of buildings according to I_{vf}-Recane (by author)



a) Ferreira b) Vicente

Figure 7. Spatial distribution of I_{vf} for existing state of the buildings in Vrutok; (by author)



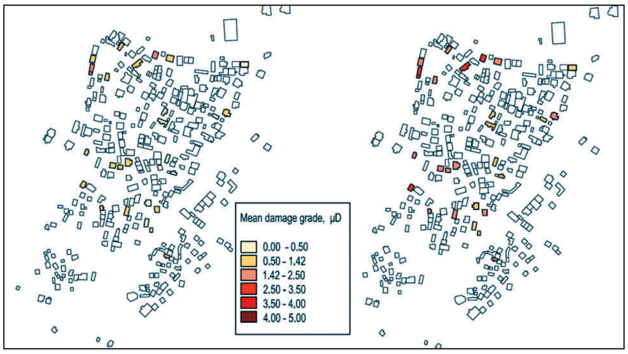
a) Ferreira b) Vicente

Figure 8. Spatial distribution of I_{vf} for existing state of the buildings in Recane (by author)

3.2. Distribution and Scenarios of Damages

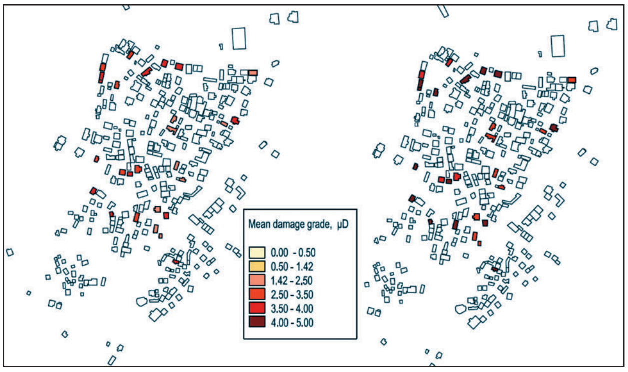
With the calculated values of the vulnerability index, using equation (3), the mean damage grade (μ_D), was calculated, for 4 different scenarios of macro seismic intensities (between VI and IX degrees according to the MCS scale) (Bernardini et all., 2007). A graphical representation of the spatial distribution of the average damage level at earthquake intensities from I=6 to I=9 degrees for buildings in village Vrutok is shown in figures 9 and 10.

Figures 11 and 12 show statistical data on the percentage representation of the mean damage grade achieved for each of four separate scenarios in village Vrutok.



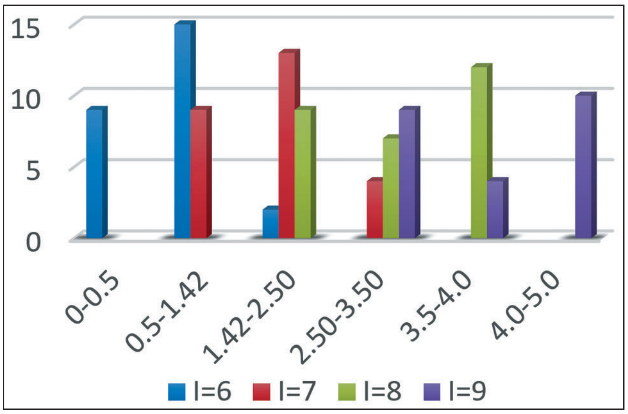
a) I=6 b) I=7

Figure 9. Spatial distribution of the mean damage grade (μ_D) for different earthquake intensities in the buildings in Vrutok (by author)



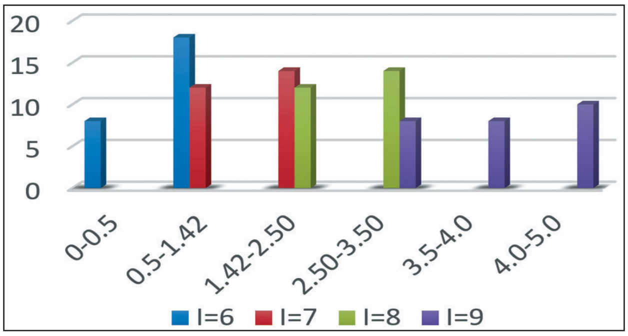
a) I=8 b) I=9

Figure 10. Spatial distribution of the mean damage grade (μ_D) for different earthquake intensities in the buildings in Vrutok (by author)



Ferreira

Figure 11. Percentage distribution of buildings according to the mean damage grade (μ_D) of buildings in Vrutok (by author)

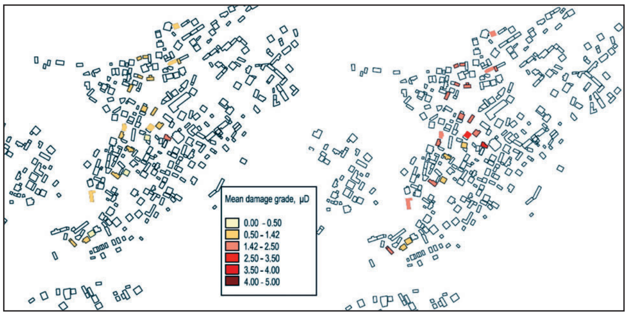


Vicente

Figure 12. Percentage distribution of buildings according to the mean damage grade (μ_D) of buildings in Vrutok (by author)

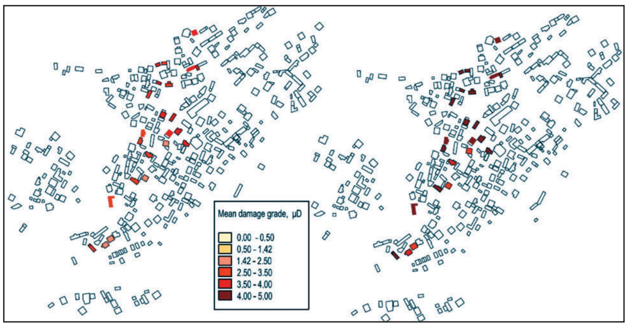
A graphical representation of the spatial distribution of the average damage level at earthquake intensities from I=6 to I=9 degrees for buildings in village Recane is shown in figures 13 and 14.

Figures 15 and 16 show statistical data on the percentage representation of the mean damage grade achieved for each of four separate scenarios in village Recane.



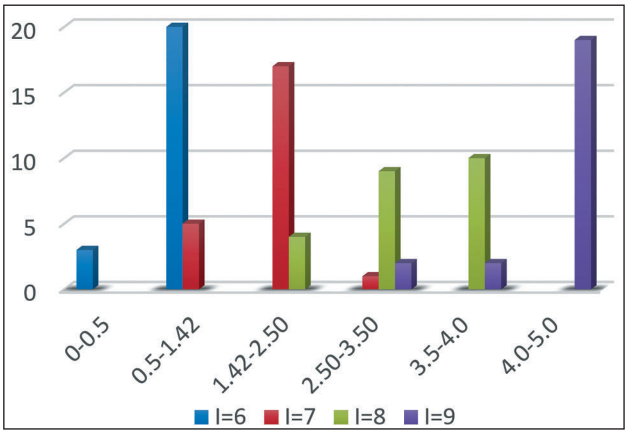
a) I=6 b) I=7

Figure 13. Spatial distribution of the mean damage grade (μ_D) for different earthquake intensities in the buildings in Recane (by author)



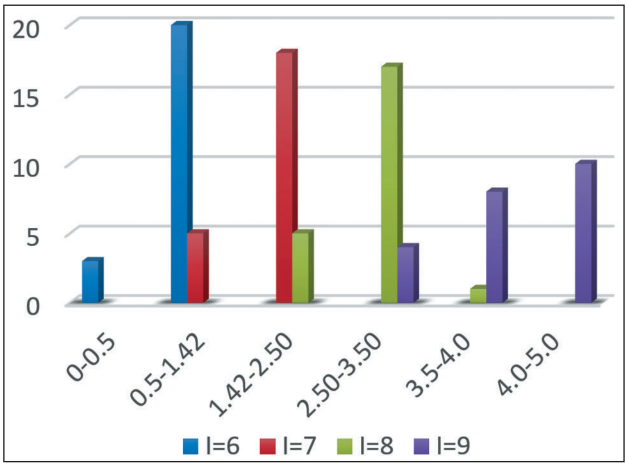
a) I=8 b) I=9

Figure 14. Spatial distribution of the mean damage grade (μ_D) for different earthquake intensities in the buildings in Recane (by author)



Ferreira

Figure 15. Percentage distribution of buildings according to the mean damage grade (μ_D) of buildings in Recane (by author)



b) Vicente

Figure 16. Percentage distribution of buildings according to the mean damage grade (μ_D) of buildings in Recane (by author)

According to the obtained results, it is noted that for the lower intensities of the earthquake (VI and VII degree), the buildings in the village of Vrutok are valued with scores from 0 to 2.5, in the village of Recane, on other hand, for intensity (VI and VII degrees), the buildings are valued with from 0 to 2.5.

For the higher intensities of the earthquake (VIII and IX degrees) in both villages, the buildings are rated 2.5 to 5.

The vulnerability curves for the current state of the buildings in the village of Vrutok and village of Recane is shown in figures 17 and 18.

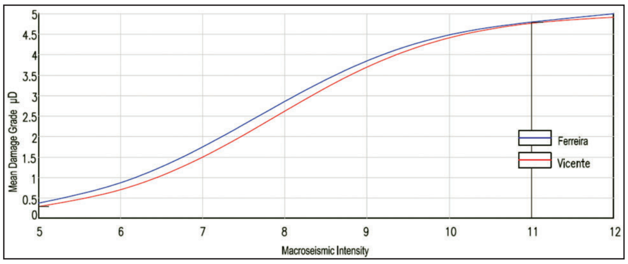


Figure 17. Vulnerability curves for the current state of the buildings in the village of Vrutok

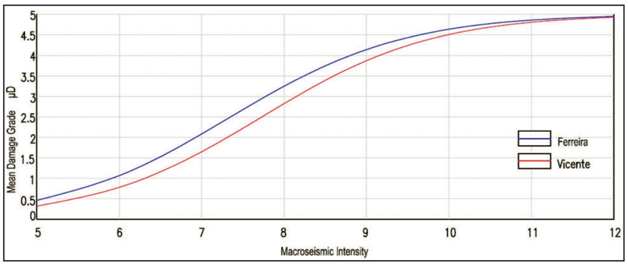


Figure 18. Vulnerability curves for the current state of the buildings in the village of Recane

The necessary data for a total of 49 buildings were collected and the seismic vulnerability index method was applied. Although the examined region is a medium-level seismic hazard zone, the results showed that significant damage could occur in a possible medium and high-level earthquake. According to the results obtained, while a large part of the buildings would be significantly damaged in a possible earthquake of magnitude 7, a large part of the buildings would be destroyed or would be rendered unusable in a possible earthquake of magnitude 8 and 9.

4. Conclusion and discussion

Masonry buildings occupy a large place in the current building stock of the Republic of North Macedonia. The percentage of existing masonry buildings in rural areas is even higher. Apart from the fact that many people live in them, these buildings have architectural value, which should be preserved.

In rural areas, lack of maintenance and inadequate rehabilitation of buildings increase the seismic vulnerability of buildings. To prevent any kind of loss caused by earthquakes, the vulnerability of existing buildings must be assessed, and the necessary reinforcement works must be carried out. To achieve this, studies based on macro seismic approaches are important for examining the existing building stock.

Within the scope of the research, a total of 49 masonry buildings in both villages were evaluated using the vulnerability index method (VIM). Thus, results were obtained regarding the vulnerability of buildings in the event of a possible earthquake in the region and risky buildings in both villages were identified. According to the results obtained, in a possible magnitude 8 earthquake, 70% of the buildings in the village of Vrutok could be severely damaged or destroyed, while in the village of Recane, 82% of the buildings could be severely damaged or destroyed. In a possible magnitude 9 earthquake, all masonry structures in both villages could be severely damaged and destroyed. With the obtained results, a picture of the state of vulnerability of the investigated buildings or areas is obtained. After defining buildings or areas that have high risk in even of a future earthquake, it is possible to make decisions about further steps to improve the situation.

The next steps after this research can be as follows:

- Investigating the buildings at risk in more detail with the obtained database, performing non-linear numerical analyses.
- Comparing the results to be obtained with these analyses with the existing results, thus improving the VIM methodology.
- Creating risk scenarios with the general results obtained.
- Using all the obtained data to prepare improvement projects with local governments.

References

1. *Bernardini, A., Giovinazzi, S., Lagomarsino, S., Parodi, S., Bernardini, S. G. A., (2007). "Vulnerabilità e previsione di danno a scala territoriale secondo una metodologia macrosismica coerente con la scala EMS-98", em In Proceedings of the 12th Conference of the Italian National Association of Earthquake Engineering - ANIDIS.*
2. *Ferreira, T.M., (2010) "Seismic Vulnerability Assessment of Old Urban Centres - Case Study of the Old City Centre of Seixal, Portugal". Thesis of the post-graduate course in Rehabilitation of the Built Heritage, Faculty of Engineering of the University of Porto, Portugal.*
3. *Ferreira, T., Vicente, R., Varum, H. (2014). "Seismic vulnerability assessment of masonry façade walls: Development, application and validation of a new scoring method." Structural engineering & mechanics. Vol.50. No.5, pp. 541-561. DOI: 10.12989/sem.2014.50.4.541*
4. *Ferreira, T.M., Mario, R., Vicente, R. (2017). "Vulnerability Assessment of the Old City Centre of Horta Portugal: Calibration and Application of a Scoring Method". 16th World Conference on Earthquake Engineering, 16WCEE 2017, Santiago, Chile.*
5. *Lumantarna, E., Lam, N, Tsang, H, Wilson, J., Gad, E., and Goldsworthy, H. (2014). "Review of Methodologies for Seismic Vulnerability Assessment of Buildings". Australian Earthquake Engineering Society 2014 Conference, Nov. 21−23 Lorne, Australia.*
6. *Nikolic, Z., Runjic, L., Ostojic Skomrlj, N., Benvenuti, E. (2021). "Seismic Vulnerability Assessment of Historical Masonry Buildings in Croatian Coastal Area". Applied Sciences, Vol. 11 No. 13, pp. 5997. https://doi.org/10.3390/app11135997*
7. *Speranza, E. (2003). "An Integrated Method for the Assessment of the Seisimic Vulnerability of Historic Buildings". Phd thesis, University of Bath, UK.*
8. *Vicente, R.D. (2008). "Estrategias e metodologias para interveneçoes de reabilitaçao urbana Avaliaçao da vulnerabilidade e do risco sismico do edificado de Baixa de Coimbra".*
9. *Vicente, R., Parodi, S., Lagomarsino, S., Varum, H., Mendes Silva, J. A. R. (2011). "Seismic vulnerability and risk assessment: case study of the historic city centre of Coimbra, Portugal", Bull Earthquake Eng. No. 9, pp.1067–1096. DOI 10.1007/s10518-010-9233-3.*
10. *URL-1. Available at: https://en.wikipedia.org/wiki/Rećane,_Gostivar#/media/File:Поглед_на_Речане.jpg (accessed 15 June.2024)*
11. *URL-2. Total resident population of the Republic of North Macedonia by ethnic affiliation, by settlement, Census 2021. Available at: PxWeb (accessed 15 June. 2024)*
12. *URL-3. Available at: https://en.wikipedia.org/wiki/Vrutok#/media/File:Поглед_на_Врутok.jpg (accessed 15 June.2024)*
13. *URL-3. https://en.wikipedia.org/wiki/Vrutok#/media/File:Поглед_на_Врутok.jpg Last Accessed:15.06.2024*

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