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METHODOLOGY FOR ASSESSING THE VULNERABILITY OF EXISTING MASONRY BUILDINGS: CASE STUDY OF GOSTIVAR CITY

Seismic vulnerability assessment of masonry structures is a very important issue even for regions with moderate to low seismic hazard. This is even more important when dealing with old buildings, such as the buildings located in the geographical area of interest, where all masonry structures were built in nineteenth century and in the first half of the twentieth century, that is, before the adoption of the aseismic design regulation. Although most of the masonry building stock in the researched region consists of residential buildings, there are also public and religious buildings. As a result of the field studies, it was determined that many people lived in these buildings. The uncertain behavior of masonry structures during earthquakes shows that people living in these residences are at risk. In this context, the aim of the research is to examine the building stock of masonry structures to evaluate the seismic risk in the region. There are different methods for assessing the vulnerability of structures. The purpose of the research, scope of the study, available resources, etc. should be considered when choosing the appropriate methodology. This paper presents a methodology for assessing the seismic vulnerability of existing masonry structures and the results obtained from the application of the methodology for the city of Gostivar.

Keywords: masonry structures, seismic risk, vulnerability assessment, vulnerability index, urban areas

1. INTRODUCTION

The high sensitivity of today's technologies, large cities built in seismic hazard zones are some of the reasons for the increase in losses from natural disasters in recent years [1]. All this has increased interest in the development of seismic assessment methodologies as well as solutions for reinforcing existing building stocks [2].

It is necessary to construct buildings in accordance with the seismic design rules to ensure seismic safety. However, existing

buildings do not meet these rules, which has led to the need to estimate the vulnerability of existing buildings [3].

The assessment of the vulnerability of buildings can be defined as their susceptibility to damage at a certain earthquake intensity. In the past, many methods have been proposed to assess seismic vulnerability [4].

These methods are used from single buildings to large urban areas. To select the right method, the purpose of the research, the available resources, the approach to obtaining information, the economic situation and the computational effort should be taken into consideration [5].

1.1 METHODS FOR VULNERABILITY ASSESSMENT

To determine the seismic vulnerability of a building, there is a need to establish a correlation that can provide the expected damage level for each seismic intensity level and define appropriate parameters to measure damage and severity [6].

Different vulnerability assessment methods have been proposed and applied in the past. They can be classified generally into two groups: empirical and analytical, both groups can be used in hybrid methods [7].

2. METHODOLOGY FOR SEISMIC VULNERABILITY ASSESSMENT OF MASONRY BUILDINGS

The seismic vulnerability assessment of many buildings in an urban environment is a difficult and complicated task because it is not rational to perform nonlinear analysis of all buildings. To solve this, vulnerability curves obtained by numerical analysis and statistical processing of the results for a class of buildings can be defined. Vulnerability curves relate to the probability of exceeding a certain damage level for a given earthquake intensity [8] [9] [10].

Various studies have been conducted using vulnerability curves to assess seismic vulnerability and damage scenarios of buildings in urban centers and to determine basic critical situations. Empirical methods such as the vulnerability class method and the vulnerability index method are widely used methods to define the vulnerability of buildings in urban areas. In this research, the Vulnerability Index (VIM) method was used to assess the vulnerability of the selected buildings in

Gostivar. The vulnerability index method (VIM) is based on the statistical relationship between macroseismic intensity and apparent or observed damage observed in previous earthquakes, as well as the fact that different structural classes tend to experience the same or similar types of damage. The vulnerability index method was originally developed by Benedetti and Petrini [11] [12].

This method, called an indirect method since the relationship between seismic action and response is established through the sensitivity index, is based on a large amount of data obtained from the detected damages. According to this classification, the vulnerability index of each building is evaluated using the following formula:

$$I_{vf}^* = \sum_{i=1}^{11} C_{vi} \cdot P_{vi} \quad (1)$$

The vulnerability index (I_{vf}^*) is calculated as a scaled sum of 14 parameters where each parameter is defined by a weighting factor P_{vi} , and each parameter is associated with four classes (C_{vi} – A, B, C, D) from (A – optimal) to (D – unfavorable). Later, Vicente made additions and added 3 more parameters to the existing 11 parameters [5]. Ferreira also made additions and calibrated according to the data from the 1998 Azores earthquake [13]. After these calibrations, the method was used to assess the seismic vulnerability of different historical city centers. With the changes made, the final formula is as follows:

$$I_{vf}^* = \sum_{i=1}^{14} C_{vi} \cdot P_{vi} \quad (2)$$

The methodology used in this study is based on the calculation of a vulnerability index for each building. The vulnerability index is calculated as the sum of the determined values of the seismic responses of 14 parameters for each building (Table1).

Table 1. Parameters for calculating vulnerability index [5] [13]

Parameters	Class (C _{vi}) A B C D	Weight Factor P _{vi}	
		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

For each parameter, a weighting factor P_{vi} , with a value between 0.5 and 2.5, is determined according to its contribution to the examined

building. The weighting factors P_{vi} , are evaluated in four vulnerability classes C_{vi} (A, B, C, D) where (A – optimal) to (D – unfavorable).

2.1 VERIFICATION FOR THE PROPOSED METHODOLOGY

The vulnerability index method is like the GNDT II (National Group for Earthquake Defense) proposal. GNDT II is developed with this method, but it allows correlation between data because important parameters are similar [14]. This equivalence allows the validation of the proposed methodology and its correlation with the macroseismic methodology of Giovinazzi and Lagomarsino [15] and allows the construction of damage and loss scenarios.

The methodology developed by Benedetti and Petrini (1984) uses the vulnerability index as an intermediate step in the damage assessment process for buildings subjected to a certain level of seismic action. This deterministic correlation between seismic action (expressed in terms of PGA) and damage (expressed as a vulnerability index ranging from 0 to 1) represents the quotient between the costs of repairing and replacing the original undamaged condition, referring to the present value of the structure. When using the vulnerability curves of the macroseismic methodology proposed by Giovinazzi and Lagomarsino [15], it is essential that they correspond to the GNDT II methodology [14], due to its similarity with the proposed methodology. The macroseismic methodology is based on the definition of building typologies belonging to vulnerability classes, damage classifications and intensity levels according to the European Macroseismic Scale EMS-98 defined by Grünthal [16].

In the macroseismic methodology, vulnerability is also expressed by a numerical value, the vulnerability index (V), which varies from 0 to 1, initially defined according to typological information (type of construction), which is then adjusted with scores attributed to the modified parameters. These parameters depend on the unique characteristics of buildings [17], such as: building condition, quality of materials and construction, number of floors, irregularities, etc. From this value of the vulnerability index (V), a vulnerability function is constructed, translated into an analytical expression of the building or typology of buildings for different EMS-98 macroseismic intensities [16]. In this way, expression (3) is obtained, which allows the calculation of the average damage level (μ_D), defined in the range from 0 to 5.

$$\mu_D = 2.5 \left[1 + \tanh \left(\frac{I+6.25-13.1}{Q} \right) \right], \quad (3)$$

$$0 \leq \mu_D \leq 5$$

The value of the intermediate damage level μ_D depends on the fragility index (V), macroseismic intensity (I) and ductility factor (Q), which can vary from 1 to 4. According to the latest calibrations, it has been determined that the most suitable value for masonry buildings is the ductility factor $Q = 2.0$ [18].

The damage assessment according to the Petrini and Benedetti methodology [11] is expressed as an index of the mean damage value, table 2. This damage index is correlated with the mean damage level (μ_D), given by the macroseismic methodology, which represents the average value of the damage degree (p_k) and is used for the discretized damage degree (D_k), (Table 2), expressed as:

$$\mu_D = \sum_{k=0}^5 p_k \cdot D_k \quad (4)$$

Table 2. Division of damage by factor and average level of damage

Discretized degree of damage	Damage factor DF	Medium level of damage μ_D
D0- No damage	0.00	[0.00 – 0.50]
D1- Slight damage	0.01	[0.50 – 1.42]
D2- Moderate damage	0.10	[1.42 – 2.50]
D3 – Major damage	0.35	[2.50 – 3.50]
D4 – Very major damage	0.75	[3.50 – 4.00]
D5 - Destroyed	1.00	[4.00 – 5.00]

For ease of application, the relationship between the average damage index value (DF) and the average damage value (μ_D) is converted into an analytical expression given by equation (5), and the correlation of the two procedures is shown in table 3.

$$\mu_D = 4 \cdot DF^{0.45} \quad (5)$$

Table 3. Correlation between vulnerability index of two procedures [19]

GNDT Methodology	$I_v = 45$	$I_v = 20$	$I_v = -5$
Macroseismic methodology	Class A (V = 0.88)	Class B (V = 0.72)	Class C (V = 0.56)

Based on this comparison, it is possible to define an analytical linear correlation between the vulnerability indexes of the two methodologies (V and I_v):

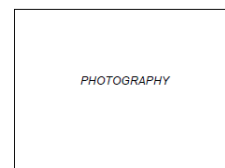
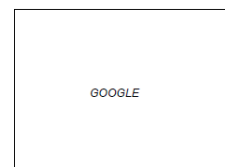
$$V = 0.592 + 0.0057 \cdot I_v \quad (6)$$

3. APPLICATION OF SEISMIC VULNERABILITY ASSESSMENT METHODOLOGY IN GOSTIVAR

According to the proposed methodology of Vicente, a data collection form for field research is proposed. The parameters of the vulnerability index methodology are adapted to the research area. The aim is to collect more accurate information needed for the assessment of the seismic vulnerability of buildings more quickly. Figures 1 and 2 show the proposed data collection form, while Figure 3 shows an example of completed forms from field research.

BUILDING IDENTIFICATION

Row no:
City:
Street:
Number: Postal Code:
Lon: _____ Lat: _____
Contact: _____
Tel: _____
e-mail: _____
Year of construction: _____
Area (m²): _____
Purpose: _____



INFORMATION ABOUT CONSTRUCTION

P1- Masonry Type

- a) - Framed Masonry
- b) - Ashlar masonry
- c) - Brick
- d) - Adobe/ Rubble masonry

P3- Conventional strength

Masonry	Mortar	Reduced rigidity
a) Framed	Cement	1.00
b) Stone	Lime/Cement	0.83
c) Brick	Lime	0.97
d) Adobe	Mud	0.50

P5- Number of floors

- a) - 1
- b) - 2
- c) - 3 until 4
- d) - >5 (extensions/superstructures)

P2 - Quality of the structural system

- a) - good quality of masonry
- b) - irregular stone masonry
- c) - low quality
- d) - poor quality

P4- Wall thickness

- a) - $(L/S)_{max} \leq 15$
- b) - $15 < (L/S)_{max} \leq 18$
- c) - $18 < (L/S)_{max} \leq 25$
- d) - $(L/S)_{max} > 25$

P6- Location and conditions for foundations (EN 1998-1)

- a) - A
- b) - B
- c) - C
- d) - D, E

Figure 1. Form - Page 1 (by author)

P7- Building position in relation to others

a) b) c) d) e)

P8- Irregularity in basement

a) up to 10%
b) from 10% to 20%
c) from 20% to 30%
d) more than 30%

P9-Height irregularity

a) - 0%
b) - up to % 10
c) - (10-20)%
d) - (20-30) %

P10- Layout of openings

a) In line
b) Horizontal irregularities
c) Horizontal and vertical irregularities
d) Large openings on the ground floor

P11 - Horizontal diaphragms

a) Rigid and well-bound
b) Flexible and well-bound
c) Rigid and loosely bound
d) Flexible and loosely bound

P12-Roof construction

a) Roofs with trusses, support columns and other roof elements
b) Roofs with trusses only
c) Roofs without trusses with perimeter supports
d) Roofs without trusses and perimeter supports

P13-Damage

a) - Good condition
b) - Small cracks (less than 0.5 mm)
c) - Cracks (2-3mm)
d) - Major damage

P14- Non-constructive elements

a) - no non-constructive elements
b) - presence of small non-constructive elements
c) - small non-constructive elements - poorly connected
d) - presence of chimneys and non-constructive elements outside the structure

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
C _{vf}	A													
	B													
	C													
	D													

Figure 2. Form - Page 2 (by author)

BUILDING IDENTIFICATION

Name: _____
Address: _____
Municipality: _____
Cadastral number: _____
Year built: _____
Floor: _____

PHOTOGRAPHS

INFORMATION ABOUT CONSTRUCTION

A) Building type

a) Residential
b) Commercial
c) Industrial
d) Other

B) Building category

a) Category I
b) Category II
c) Category III
d) Category IV

C) Building design

a) Single-story
b) Two-story
c) Three-story
d) Four-story

D) Building materials

a) Masonry
b) Concrete
c) Steel
d) Other

E) Building condition

a) Good
b) Fair
c) Poor
d) Very poor

F) Building location

a) In the center of the city
b) On the edge of the city
c) In a rural area
d) In a mountainous area

G) Building height

a) Up to 10m
b) 10-20m
c) 20-30m
d) More than 30m

H) Building area

a) Up to 100m²
b) 100-200m²
c) 200-300m²
d) More than 300m²

I) Building foundation

a) Foundation on soil
b) Foundation on rock
c) Foundation on concrete
d) Foundation on other material

J) Building orientation

a) North
b) South
c) East
d) West

K) Building shape

a) Rectangular
b) Irregular
c) Circular
d) Other

L) Building color

a) White
b) Gray
c) Red
d) Other

M) Building roof

a) Flat
b) Gabled
c) Hip
d) Other

N) Building walls

a) Solid
b) Hollow
c) Composite
d) Other

O) Building floor

a) Concrete
b) Masonry
c) Steel
d) Other

P) Building stairs

a) Stairs on the side
b) Stairs in the center
c) Stairs in the basement
d) Stairs in the attic

Q) Building elevator

a) No elevator
b) Elevator in the center
c) Elevator in the basement
d) Elevator in the attic

R) Building parking

a) No parking
b) Parking in the center
c) Parking in the basement
d) Parking in the attic

S) Building security

a) No security
b) Security in the center
c) Security in the basement
d) Security in the attic

T) Building accessibility

a) No accessibility
b) Accessibility in the center
c) Accessibility in the basement
d) Accessibility in the attic

U) Building energy

a) No energy
b) Energy in the center
c) Energy in the basement
d) Energy in the attic

V) Building water

a) No water
b) Water in the center
c) Water in the basement
d) Water in the attic

W) Building gas

a) No gas
b) Gas in the center
c) Gas in the basement
d) Gas in the attic

X) Building electricity

a) No electricity
b) Electricity in the center
c) Electricity in the basement
d) Electricity in the attic

Y) Building telephone

a) No telephone
b) Telephone in the center
c) Telephone in the basement
d) Telephone in the attic

Z) Building internet

a) No internet
b) Internet in the center
c) Internet in the basement
d) Internet in the attic

AA) Building satellite

a) No satellite
b) Satellite in the center
c) Satellite in the basement
d) Satellite in the attic

AB) Building radio

a) No radio
b) Radio in the center
c) Radio in the basement
d) Radio in the attic

AC) Building television

a) No television
b) Television in the center
c) Television in the basement
d) Television in the attic

AD) Building computer

a) No computer
b) Computer in the center
c) Computer in the basement
d) Computer in the attic

AE) Building mobile phone

a) No mobile phone
b) Mobile phone in the center
c) Mobile phone in the basement
d) Mobile phone in the attic

AF) Building camera

a) No camera
b) Camera in the center
c) Camera in the basement
d) Camera in the attic

AG) Building microphone

a) No microphone
b) Microphone in the center
c) Microphone in the basement
d) Microphone in the attic

AH) Building speaker

a) No speaker
b) Speaker in the center
c) Speaker in the basement
d) Speaker in the attic

AI) Building monitor

a) No monitor
b) Monitor in the center
c) Monitor in the basement
d) Monitor in the attic

AJ) Building keyboard

a) No keyboard
b) Keyboard in the center
c) Keyboard in the basement
d) Keyboard in the attic

AK) Building mouse

a) No mouse
b) Mouse in the center
c) Mouse in the basement
d) Mouse in the attic

AL) Building printer

a) No printer
b) Printer in the center
c) Printer in the basement
d) Printer in the attic

AM) Building scanner

a) No scanner
b) Scanner in the center
c) Scanner in the basement
d) Scanner in the attic

AN) Building fax

a) No fax
b) Fax in the center
c) Fax in the basement
d) Fax in the attic

AO) Building modem

a) No modem
b) Modem in the center
c) Modem in the basement
d) Modem in the attic

AP) Building router

a) No router
b) Router in the center
c) Router in the basement
d) Router in the attic

AQ) Building switch

a) No switch
b) Switch in the center
c) Switch in the basement
d) Switch in the attic

AR) Building plug

a) No plug
b) Plug in the center
c) Plug in the basement
d) Plug in the attic

AS) Building outlet

a) No outlet
b) Outlet in the center
c) Outlet in the basement
d) Outlet in the attic

AT) Building cable

a) No cable
b) Cable in the center
c) Cable in the basement
d) Cable in the attic

AU) Building antenna

a) No antenna
b) Antenna in the center
c) Antenna in the basement
d) Antenna in the attic

AV) Building tower

a) No tower
b) Tower in the center
c) Tower in the basement
d) Tower in the attic

AW) Building mast

a) No mast
b) Mast in the center
c) Mast in the basement
d) Mast in the attic

AX) Building pole

a) No pole
b) Pole in the center
c) Pole in the basement
d) Pole in the attic

AY) Building post

a) No post
b) Post in the center
c) Post in the basement
d) Post in the attic

AZ) Building stake

a) No stake
b) Stake in the center
c) Stake in the basement
d) Stake in the attic

BA) Building nail

a) No nail
b) Nail in the center
c) Nail in the basement
d) Nail in the attic

BB) Building screw

a) No screw
b) Screw in the center
c) Screw in the basement
d) Screw in the attic

BC) Building bolt

a) No bolt
b) Bolt in the center
c) Bolt in the basement
d) Bolt in the attic

BD) Building nut

a) No nut
b) Nut in the center
c) Nut in the basement
d) Nut in the attic

BE) Building washer

a) No washer
b) Washer in the center
c) Washer in the basement
d) Washer in the attic

BF) Building gasket

a) No gasket
b) Gasket in the center
c) Gasket in the basement
d) Gasket in the attic

BG) Building seal

a) No seal
b) Seal in the center
c) Seal in the basement
d) Seal in the attic

BH) Building glue

a) No glue
b) Glue in the center
c) Glue in the basement
d) Glue in the attic

BI) Building resin

a) No resin
b) Resin in the center
c) Resin in the basement
d) Resin in the attic

BJ) Building epoxy

a) No epoxy
b) Epoxy in the center
c) Epoxy in the basement
d) Epoxy in the attic

BK) Building cement

a) No cement
b) Cement in the center
c) Cement in the basement
d) Cement in the attic

BL) Building mortar

a) No mortar
b) Mortar in the center
c) Mortar in the basement
d) Mortar in the attic

BM) Building plaster

a) No plaster
b) Plaster in the center
c) Plaster in the basement
d) Plaster in the attic

BN) Building paint

a) No paint
b) Paint in the center
c) Paint in the basement
d) Paint in the attic

BO) Building stain

a) No stain
b) Stain in the center
c) Stain in the basement
d) Stain in the attic

BP) Building varnish

a) No varnish
b) Varnish in the center
c) Varnish in the basement
d) Varnish in the attic

BQ) Building wax

a) No wax
b) Wax in the center
c) Wax in the basement
d) Wax in the attic

BR) Building oil

a) No oil
b) Oil in the center
c) Oil in the basement
d) Oil in the attic

BS) Building grease

a) No grease
b) Grease in the center
c) Grease in the basement
d) Grease in the attic

BT) Building soap

a) No soap
b) Soap in the center
c) Soap in the basement
d) Soap in the attic

BU) Building detergent

a) No detergent
b) Detergent in the center
c) Detergent in the basement
d) Detergent in the attic

BV) Building cleaner

a) No cleaner
b) Cleaner in the center
c) Cleaner in the basement
d) Cleaner in the attic

BW) Building disinfectant

a) No disinfectant
b) Disinfectant in the center
c) Disinfectant in the basement
d) Disinfectant in the attic

BX) Building antiseptic

a) No antiseptic
b) Antiseptic in the center
c) Antiseptic in the basement
d) Antiseptic in the attic

BY) Building antibiotic

a) No antibiotic
b) Antibiotic in the center
c) Antibiotic in the basement
d) Antibiotic in the attic

BZ) Building vaccine

a) No vaccine
b) Vaccine in the center
c) Vaccine in the basement
d) Vaccine in the attic

CA) Building serum

a) No serum
b) Serum in the center
c) Serum in the basement
d) Serum in the attic

CB) Building hormone

a) No hormone
b) Hormone in the center
c) Hormone in the basement
d) Hormone in the attic

CC) Building enzyme

a) No enzyme
b) Enzyme in the center
c) Enzyme in the basement
d) Enzyme in the attic

CD) Building vitamin

a) No vitamin
b) Vitamin in the center
c) Vitamin in the basement
d) Vitamin in the attic

CE) Building mineral

a) No mineral
b) Mineral in the center
c) Mineral in the basement
d) Mineral in the attic

CF) Building nutrient

a) No nutrient
b) Nutrient in the center
c) Nutrient in the basement
d) Nutrient in the attic

CG) Building fiber

a) No fiber
b) Fiber in the center
c) Fiber in the basement
d) Fiber in the attic

CH) Building protein

a) No protein
b) Protein in the center
c) Protein in the basement
d) Protein in the attic

CI) Building carbohydrate

a) No carbohydrate
b) Carbohydrate in the center
c) Carbohydrate in the basement
d) Carbohydrate in the attic

CJ) Building lipid

a) No lipid
b) Lipid in the center
c) Lipid in the basement
d) Lipid in the attic

CK) Building nucleic acid

a) No nucleic acid
b) Nucleic acid in the center
c) Nucleic acid in the basement
d) Nucleic acid in the attic

CL) Building cell wall

a) No cell wall
b) Cell wall in the center
c) Cell wall in the basement
d) Cell wall in the attic

CM) Building cell membrane

a) No cell membrane
b) Cell membrane in the center
c) Cell membrane in the basement
d) Cell membrane in the attic

CN) Building cell nucleus

a) No cell nucleus
b) Cell nucleus in the center
c) Cell nucleus in the basement
d) Cell nucleus in the attic

CO) Building cell organelle

a) No cell organelle
b) Cell organelle in the center
c) Cell organelle in the basement
d) Cell organelle in the attic

CP) Building cell structure

a) No cell structure
b) Cell structure in the center
c) Cell structure in the basement
d) Cell structure in the attic

CQ) Building cell function

a) No cell function
b) Cell function in the center
c) Cell function in the basement
d) Cell function in the attic

CR) Building cell behavior

a) No cell behavior
b) Cell behavior in the center
c) Cell behavior in the basement
d) Cell behavior in the attic

CS) Building cell response

a) No cell response
b) Cell response in the center
c) Cell response in the basement
d) Cell response in the attic

CT) Building cell adaptation

a) No cell adaptation
b) Cell adaptation in the center
c) Cell adaptation in the basement
d) Cell adaptation in the attic

CU) Building cell survival

a) No cell survival
b) Cell survival in the center
c) Cell survival in the basement
d) Cell survival in the attic

CV) Building cell death

a) No cell death
b) Cell death in the center
c) Cell death in the basement
d) Cell death in the attic

CW) Building cell regeneration

a) No cell regeneration
b) Cell regeneration in the center
c) Cell regeneration in the basement
d) Cell regeneration in the attic

CX) Building cell differentiation

a) No cell differentiation
b) Cell differentiation in the center
c) Cell differentiation in the basement
d) Cell differentiation in the attic

CY) Building cell specialization

a) No cell specialization
b) Cell specialization in the center
c) Cell specialization in the basement
d) Cell specialization in the attic

CZ) Building cell division

a) No cell division
b) Cell division in the center
c) Cell division in the basement
d) Cell division in the attic

CA) Building cell growth

a) No cell growth
b) Cell growth in the center
c) Cell growth in the basement
d) Cell growth in the attic

CB) Building cell development

a) No cell development
b) Cell development in the center
c) Cell development in the basement
d) Cell development in the attic

CC) Building cell maturation

a) No cell maturation
b) Cell maturation in the center
c) Cell maturation in the basement
d) Cell maturation in the attic

CD) Building cell aging

a) No cell aging
b) Cell aging in the center
c) Cell aging in the basement
d) Cell aging in the attic

CE) Building cell senescence

a) No cell senescence
b) Cell senescence in the center
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Based on the calculated values of the vulnerability index, using equation (3), the average damage level (μ_D) was calculated for different scenarios of macroseismic intensities. The study calculated 4 different scenarios of macroseismic intensities between VI and IX degrees according to the MCS scale. Figure 6 shows the statistical data for the percentage representation of the obtained average damage level for each of the four individual scenarios.

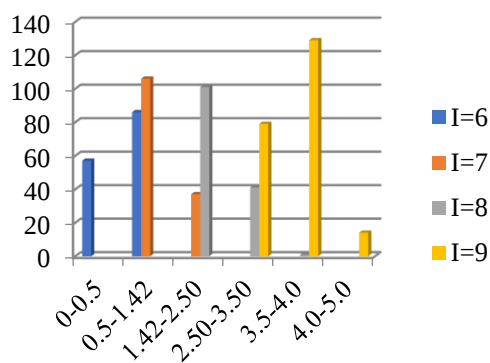


Figure 6. Percentage of buildings according to the average level of damage (μ_D)

According to the analysis of the results, it is noted that for lower earthquake intensities (VI and VII degrees), the buildings in Gostivar are evaluated with scores from 0 to 2.5. For higher earthquake intensities (VII and IX degrees), the buildings receive scores from 2.5 to 5.

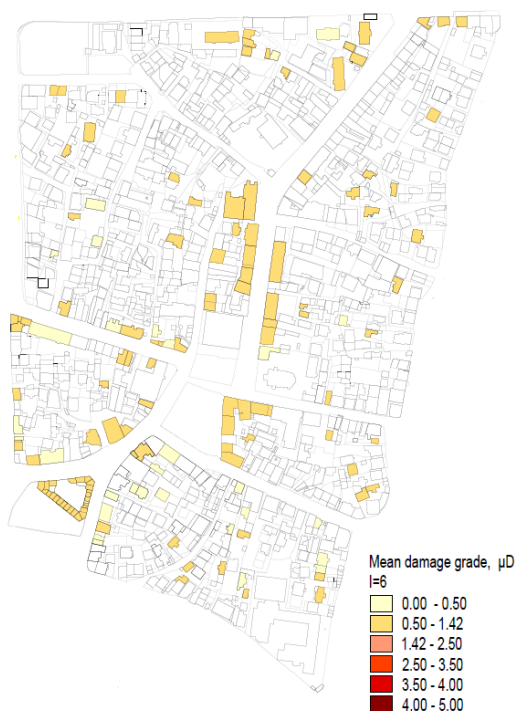


Figure 7. The spatial distribution of the average level of damage for I=6, for buildings in Gostivar

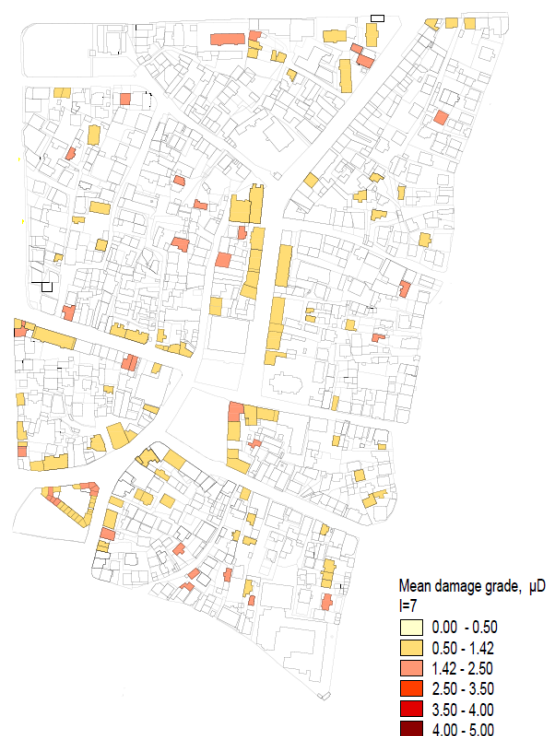


Figure 8. The spatial distribution of the average level of damage for I=7, for buildings in Gostivar

A graphical representation of the spatial distribution of the mean level of damage for earthquake intensities from I=6 to I=9 for Gostivar is shown in Figure 7,8,9 and 10.

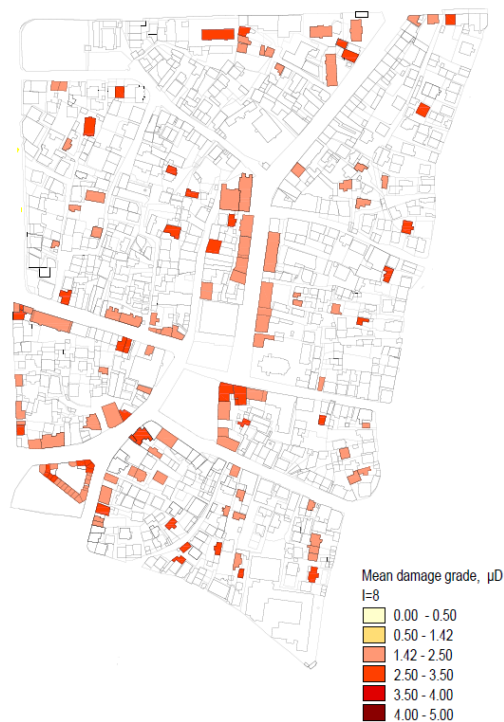


Figure 9. The spatial distribution of the average level of damage for I=8, for buildings in Gostivar

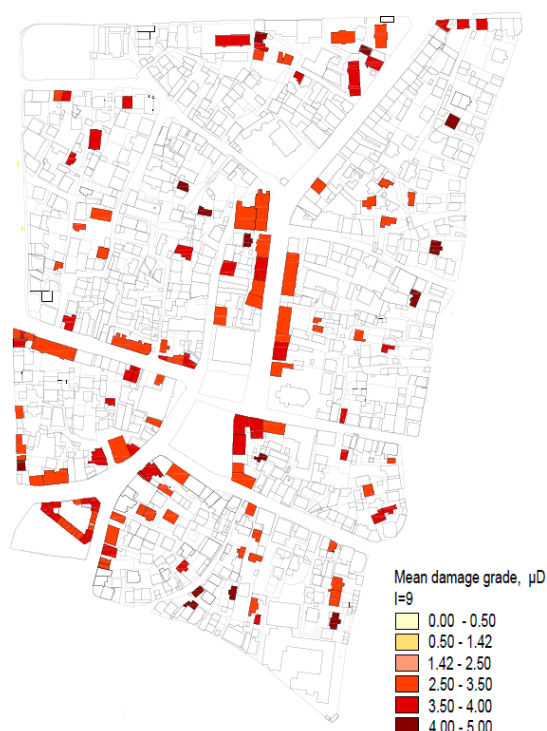


Figure 10. The spatial distribution of the average level of damage for $I=9$, for buildings in Gostivar

According to the seismic vulnerability obtained of the buildings, vulnerability curves of the masonry buildings in Gostivar were constructed depending on different macroseismic intensities (Figure 11).

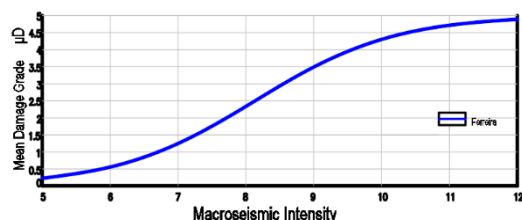


Figure 11. Vulnerability curves for the existing condition of the buildings in Gostivar

4. CONCLUSION

The aim of the study is to analyze a larger number of buildings to examine the vulnerability of existing masonry structures in urban areas. From the obtained results, a typological classification of existing masonry structures can be used to assess seismic risk at a regional level. For this purpose, the vulnerability index methodology was chosen as a methodology for assessing existing masonry structures. From the results obtained presented in the paper, most of the buildings analyzed in Gostivar would experience very large damage or even

collapse at the highest earthquake intensity. From the results obtained, buildings or areas that are at the highest risk can be identified and measures can be taken to strengthen them. A precise assessment of the vulnerability of existing buildings and the implementation of appropriate strengthening solutions can significantly reduce physical damage and economic losses from future seismic events.

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