3.3.4 Seismic vulnerability maps for HR test site

Final Version

Deliverable Number 3.3.4

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Summary

Abstract

Systematic care and planning of action to reduce seismic risk require data about seismic vulnerability and risk of the buildings. Work package WP3 of the PMO-GATE project has intended to develop exposure and vulnerability maps for the hazards considered at the test area. This Deliverable presents seismic vulnerability index map, damage index map and seismic risk map for the HR test site Kaštel Kambelovac, Croatian settlement located along the Adriatic coast. The vulnerability, damage and risk indexes of the buildings at the test site have been calculated according to the methodology and procedure shown in Deliverables 3.3.1 and 3.3.3 of the project. Developed map indicate different periods of construction of the buildings as well as the specifics of geometry, construction and materials that affect the seismic vulnerability of the buildings. The maps represent a basis for the for the seismic risk management actions.

1 Seismic vulnerability maps

1.1 Generally about basis and data for seismic vulnerability map

One of the purpose of the PMO-GATE 3.3 Activity “Assessment of climate-unrelated hazards exposure in urban and coastal areas (seismic action)” is creation of seismic vulnerability map for the buildings located in the HR test site, which was selected within the City of Kaštela.

Seismic vulnerability indexes for the buildings have been calculated according to the methodology and procedures presented in Deliverable 3.3.1 “Guidelines of the assessment procedure for earthquake vulnerability in the HR test site” [1] and Deliverable 3.3.3 “Determination of seismic vulnerability indexes for masonry historical buildings located in the HR test site” [2]. Seismic vulnerability indexes are presented in seismic vulnerability map for the HR test site.

The basis of the map was obtained through detailed geodetic survey of terrain by geodetic drone recording, where the cadastral and building parcels and topographic characteristics of the area were presented.

The geodetic basis of the HR test site and the cadastral and building parcels are shown in Figs. 1 and 2.

Fig. 1. Geodetic basis of the HR test site

Fig. 2. HR test site with marked cadastral and building parcels

The HR test site was divided firstly into two parts: historical core and the area outside of the historical core. The buildings in the historical core are mostly stone masonry, built to the end of 19th century and at the beginning of 20th century. Outside of the historical core the buildings are mostly built after the 1948 and can be classified according to the construction period. Furthermore, the part outside the historic centre is divided into northern, eastern and western parts (Fig. 3). In the northern part the buildings are partly made of stone blocks and partly of concrete or brick blocks. The eastern part has buildings mostly made of concrete or brick blocks.

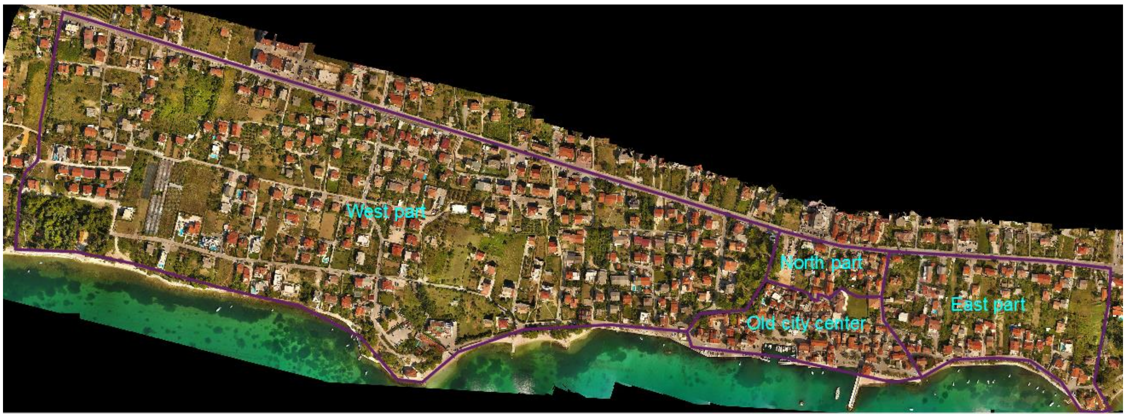


Fig. 3. Test site Kaštel Kambelovac divided into four characteristic parts

1.2 Seismic vulnerability map for historical centre

Vulnerability indexes for 75 buildings in historical centre were calculated, according the Deliverable 3.3.1. “Guidelines of the assessment procedure for earthquake vulnerability in HR test site” and Deliverable 3.3.3. Determination of seismic vulnerability indexes for masonry historical buildings located in the HR test site, and all information gathered was digitalized. Some of those buildings are located on several cadastral parcels and have different owners, but they were grouped beacause of their structural integrity. In order to improve the interpretation of the results, such individual vulnerability parametres, as well as other imortant input information, were integrated into a Geographical Information System (GIS) tool. The GIS software adopted in this study was the open-source suite ESRI ArcGIS Runtime 100.4 v1, wherein geo-referenced graphical data (vectorized information and orthophoto maps) was combined with building parameter information.

Figure 4 shows seismic vulnerability map for the buildings in historical core. The buildings were divided into 4 vulnerability classes: Low vulnerability for $I_v<30$, Medium-low vulnerability for $30<I_v<45$, Medium-high vulnerability for $45< I_v<60$, High vulnerability for $I_v>60$.

It can be observed that the largest number of buildings in the historical core belong to the class of High vulnerability (23.5%) and Medium-High vulnerability (48.1%). A small number of buildings belong to the class of Medium-Low vulnerability (17.3%). Only a few buildings are of Low vulnerability (11.1%), and they are mostly old stone buildings that have been reconstructed. Buildings with vulnerability index of 45 and more are considered highly vulnerable buildings and this result is expected given that it is an old city center.

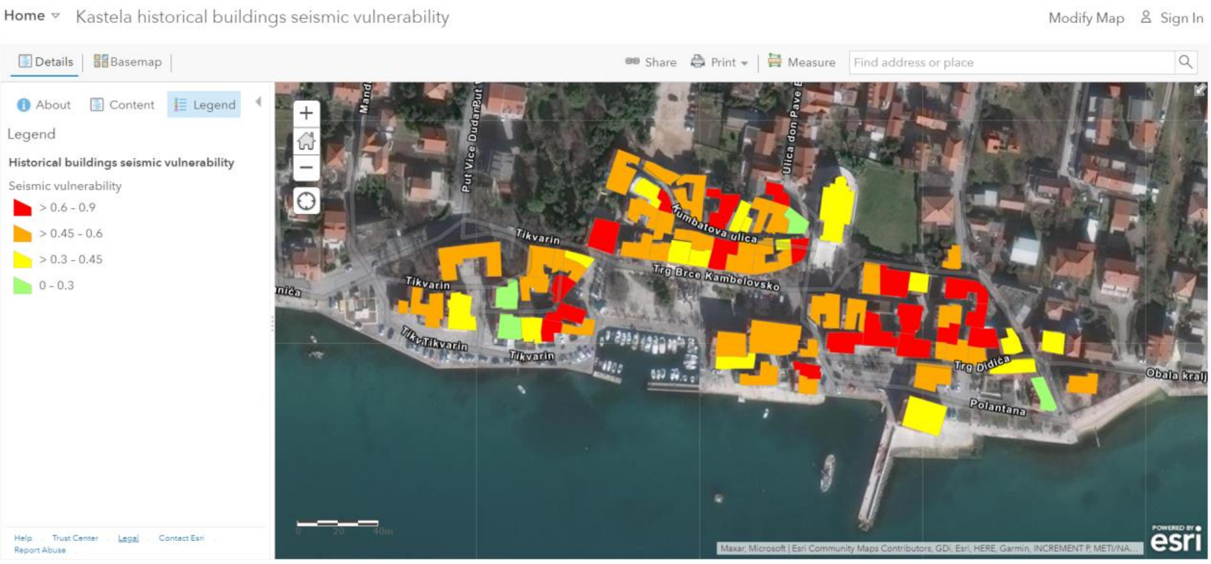


Fig. 4. Vulnerability classes of the buildings in historical core

Vulnerability index of the buildings is composed of 11 parameters [5] specifically used to evaluate the physical characteristics of the buildings accounting for their structural resistant system, material characteristics, position of the building and fondation, planimetric and elevation configuration, maximum distance between the bearing walls, influence of the roof and non-structural elements and state of conservation (condition).

The investigation of the parameters that composes the seismic vulnerability index allows for characterizing and discussing some particular indicators that can help to better understand the overall seismic vulnerability results. Therefore, spatial distribution of these parameters is analyzed and shown in Figure 5.

We firstly focused on parameter “Type and organization of the resistant system”, which measures the presence of connections among perpendicular walls and connections among floors or roofs in masonry buildings, which are necessary to ensure the three-dimensional box behaviour of the building. We detected that about 77% of the buildings were made without any confining elements and with poorly connected stone walls (class D), whereas 21% were also made without confining elements but had strongly connected walls (class C). Only 1% were in class A, having been reconstructed. Most buildings were made without confining elements (classes C and D), this being one of the main aspects that can lead to significant damage and to the separation of the walls.

The “Quality of the resistant system” parameter is based on the type of masonry, considering the type of material, the shape of the elements, and the homogeneity of the walls. Fig. 5b shows the distribution of the buildings between vulnerability classes A to D, with 3%, 3%, 57%, and 37% of buildings, respectively. The majority of them belonged to classes C and D, indicating medium to high vulnerability.

The “Conventional resistance” parameter estimates the maximum shear strength of the structure, accounting for the resistant area of the walls in the two main horizontal directions. As shown in Fig. 5c, the buildings were distributed between vulnerability classes A to D, with 1%, 16%, 68%, and 15% of the buildings, respectively.

The “Position of the building and foundation” parameter considers the influence of the local morphology of the site and the natural slope of the ground. Its distribution in Fig. 5d showed a low level of vulnerability. Specifically, 57% of buildings were in class A and 43% were in class B. The reason for such a distribution is the presence of solid soil of type A and the relatively small slope of the terrain.

The “Typology of floors” parameter evaluates the in-plane stiffness of the floor and the presence of efficient floor-to-wall connections. The buildings were distributed between vulnerability classes A to D, with 19%, 0%, 3% and 78% of buildings, respectively (Fig. 5e). The reason for this high percentage of buildings in class D is the presence of wooden floors which were poorly connected to the walls.

Regarding the parameter of “Planimetric configuration”, which measures the regularity of the planimetric shape of the building, 8%, 17%, 23%, and 52% of the buildings were distributed in vulnerability classes A to D, respectively (Fig. 5f). The most populated classes were C and D, because a high level of horizontal irregularity was detected.

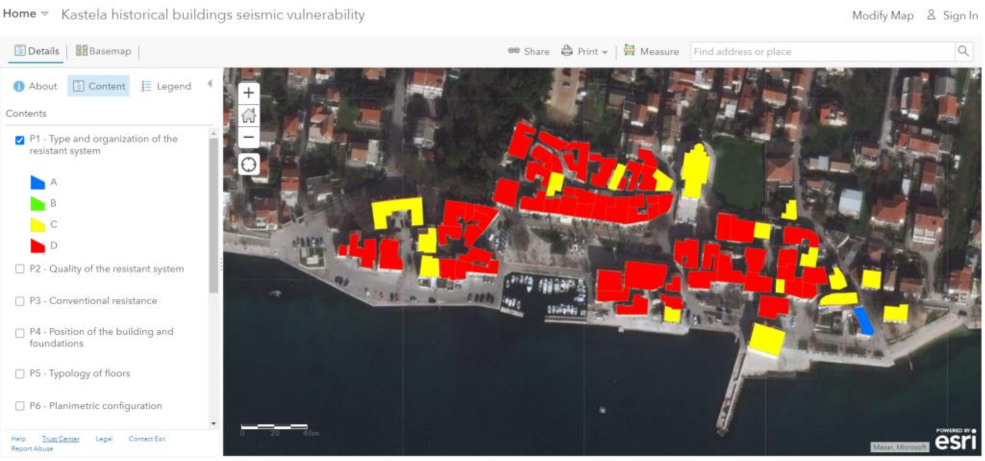
The “Elevation configuration” parameter evaluates vertical regularity through the analysis of the stiffness of different floors, the presence of porticos, lodges, towers, and other structural elements which affect the distribution of the masses at each floor. In terms of this parameter, 19%, 11%, 41%, and 29% of the buildings belonged to vulnera-bility classes A to D, respectively, as displayed in Fig. 5g, with classes C and D proving to be most relevant.

The “Maximum distance among the walls” parameter validates the presence of structural walls orthogonally connected to transversal ones. The buildings in the his-torical core had a favorable distribution, as most of them belonged to classes A and B, with 69% in class A, 12% in class B, 13% in class C, and 5% in class D, as shown in Fig. 5h.

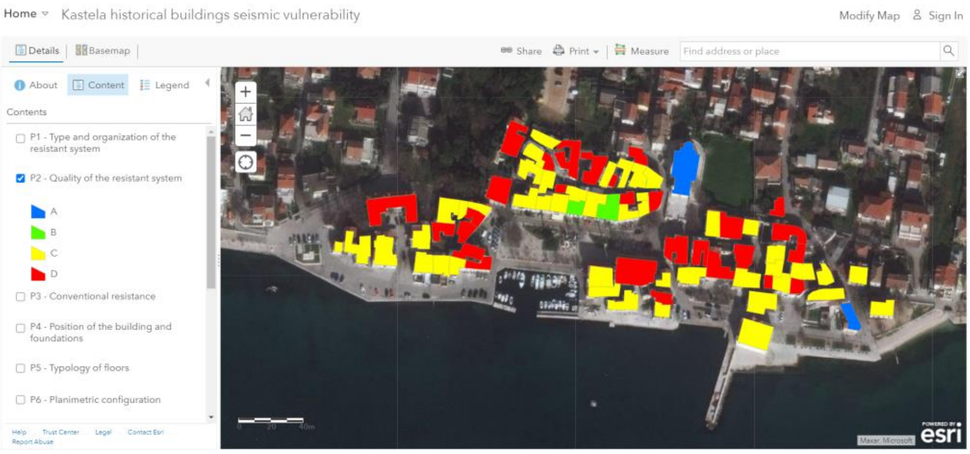
In terms of the parameter “roof”, which evaluates the roof’s typology and weight, buildings were distributed among vulnerability classes A to D, with 9%, 40%, 15%, and 36% of the buildings, respectively (Fig. 5i).

The presence of “Nonstructural elements”, which can cause damages due to fall-ing, highlighted an area of high vulnerability because most buildings had weakly con-nected nonstructural elements and belonged to classes C and D. The distribution shown in Fig. 5j was 12%, 0%, 53%, and 35% for classes A to D, respectively.

The “State of conservation” parameter analyzes the condition of the building and the presence of cracks in structural walls. The relevant distribution, shown in Figure 9k, was as follows: 27% were in class A, 0% in B, 45% in C, and 28% were in class D (Fig. 5k). Most old stone masonry buildings, which have not yet been reconstructed, are in a bad condition and belong to classes C and D, whereas reconstructed buildings are in class A.



(a) Type and organization of the resistant system



(b) Quality of the resistant system

Contents

☐ P1 - Type and organization of the resistant system

☐ P2 - Quality of the resistant system

☑ P3 - Conventional resistance

- 🟦 A
- 🟩 B
- 🟨 C
- 🟥 D

☐ P4 - Position of the building and foundations

☐ P5 - Typology of floors

☐ P6 - Planimetric configuration

(c) Conventional resistance

Contents

☐ P1 - Type and organization of the resistant system

☐ P2 - Quality of the resistant system

☐ P3 - Conventional resistance

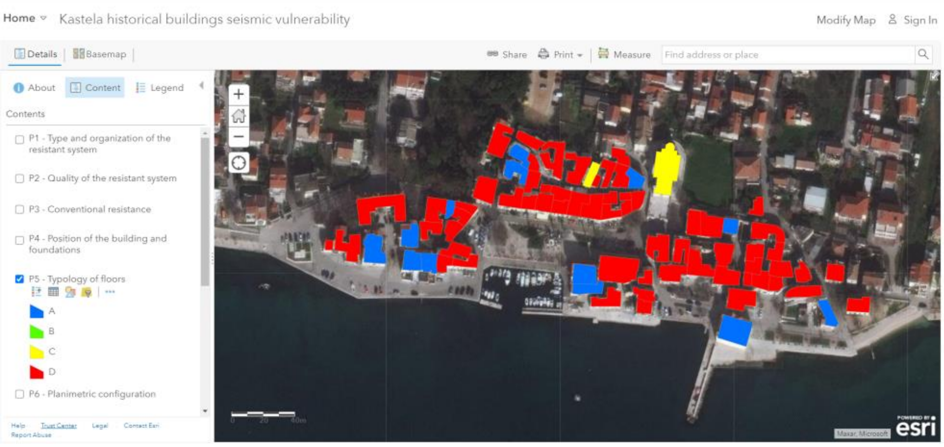
☑ P4 - Position of the building and foundations

- 🟦 A
- 🟩 B
- 🟨 C
- 🟥 D

☐ P5 - Typology of floors

☐ P6 - Planimetric configuration

(d) Position of the building and foundation



Contents

☐ P1 - Type and organization of the resistant system

☐ P2 - Quality of the resistant system

☐ P3 - Conventional resistance

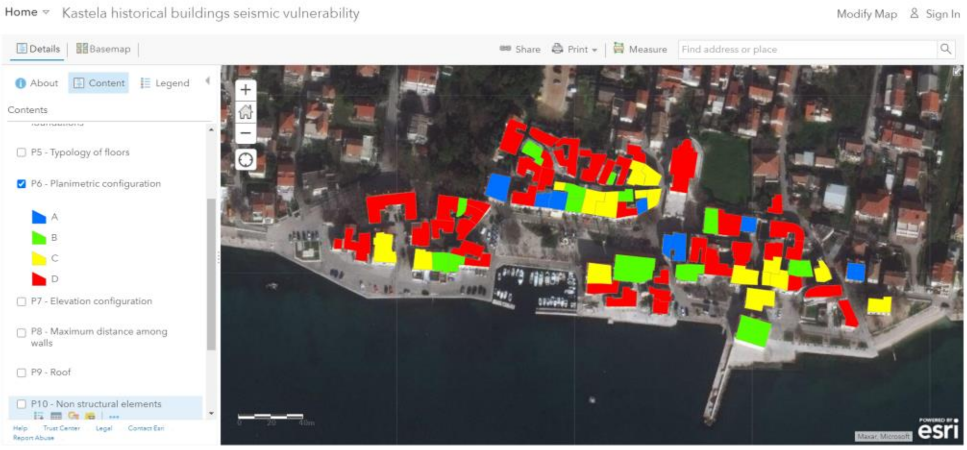
☐ P4 - Position of the building and foundations

☑ P5 - Typology of floors

- 🟦 A
- 🟩 B
- 🟨 C
- 🟥 D

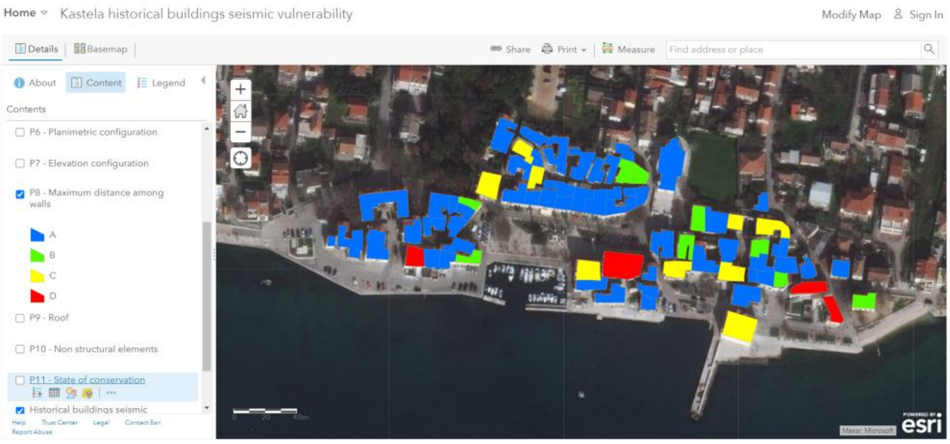
☐ P6 - Planimetric configuration

(e) Typology of floors



(f) Planimetric configuration

(g) Elevation configuration



(h) Maximum distance among walls

(i) Roof

(j) Non structural elements

☐ P8 - Maximum distance among walls
☐ P9 - Roof
☐ P10 - Non structural elements
☑ P11 - State of conservation
☑ Historical buildings seismic vulnerability

(k) State of conservation

Fig. 5. Spatial distribution of the 11 parameters that compose the seismic vulnerability index

1.3 Seismic vulnerability map for the whole test site

Fig. 6 shows, in addition to the distribution of building vulnerability indexes in the historic centre, and indexes in the northern, eastern and partially in the western parts of the test site.

In the northern part, which does not belong to the protected historic core, there are a number of stone masonry buildings. Therefore, most of the buildings belong to High, Medium-High and Medium-Low vulnerability classes. Only two buildings have Low vulnerability class.

In the eastern and western parts of the test site, the buildings are built with concrete or clay blocks, without confinement, only with confinement horizontal tie beams or with horizontal and vertical confinement. All belong to the low vulnerability class (I_V<30%). Within this class, however, there are visible differences in vulnerability. Newer buildings with clay blocks and horizontal and vertical confinement have generally the least vulnerability (less than 10%). Older buildings with concrete blocks and horizontal confinement have approximately an index between 10% and 20%. Buildings without confinement or the previous one, but irregular in height and / or layout in plan with several appendices and additions, have an index mostly between 20% and 30%. It can be noticed that not all buildings in this area had an available technical documentations. The indexes of these buildings were determined based on the estimated geometric and structural characteristics of the buildings using a geodetic survey of the area, a street view map and a visual inspection of the area, which can be influence to the values of their seismic vulnerability index.

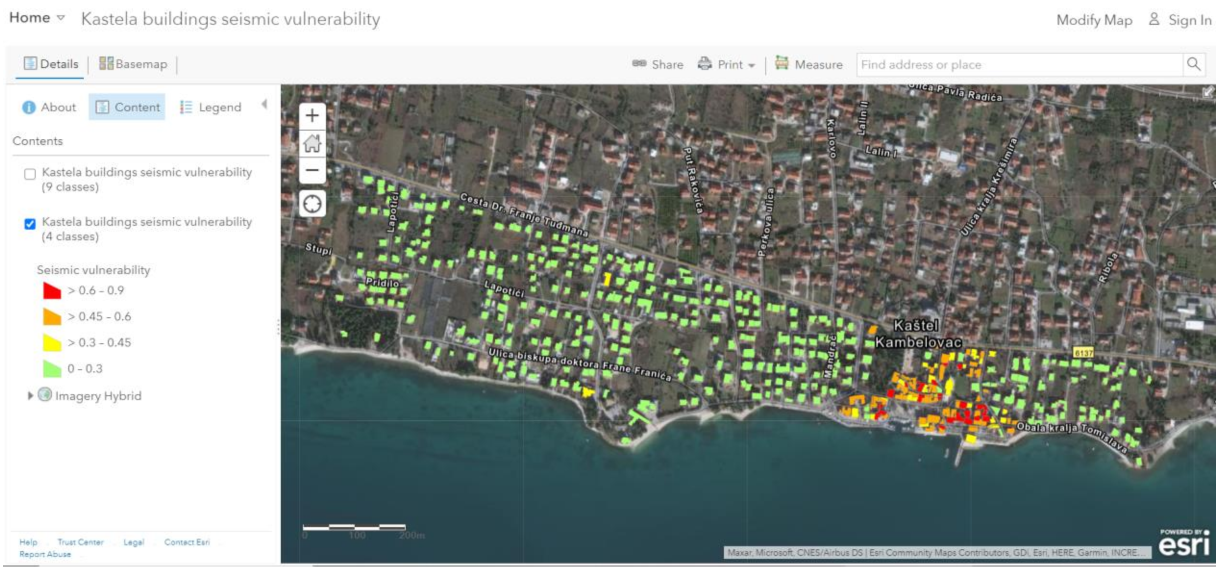


Fig. 6. Vulnerability of the buildings in the whole test site divided into 4 classes

Fig. 7 shows detail clasification of the buildings according their vulnerability indexes with division into classes of 10%.

Fig. 7. Vulnerability of the buildings - 10% division intervals

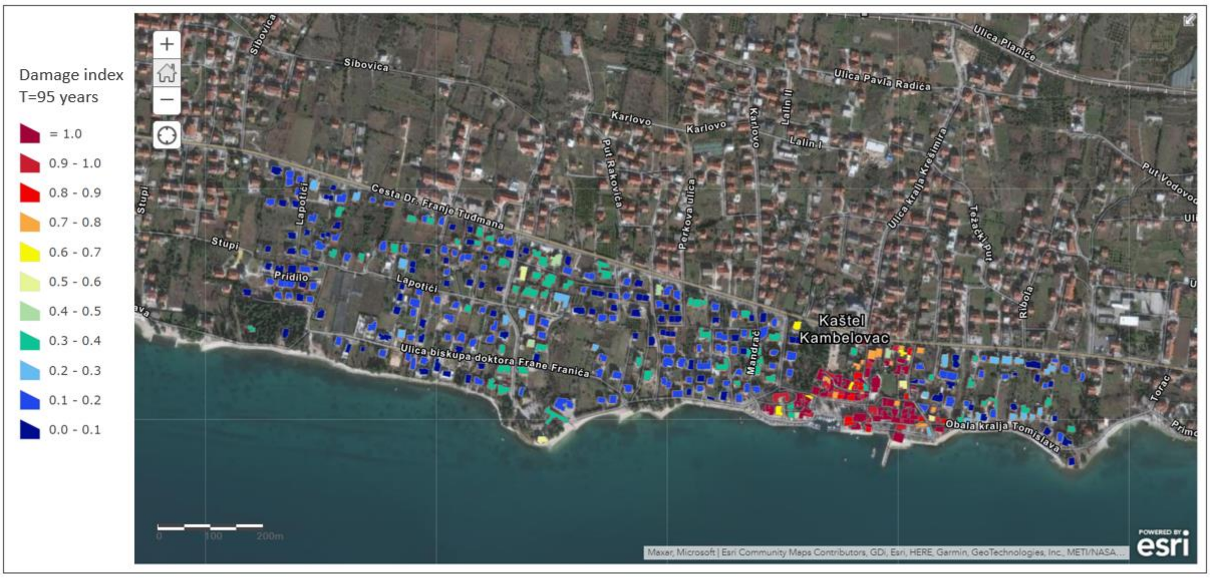
The map clearly shows the difference between the vulnerability of the historical core and the area north of the core, where mostly stone masonry buildings were built from the 15th to the beginning of the 20th century, from the rest of the area where buildings are built of concrete and clay blocks, mostly after 1950. until today.

1.4 Seismic damage maps and seismic risk maps of the HR test site

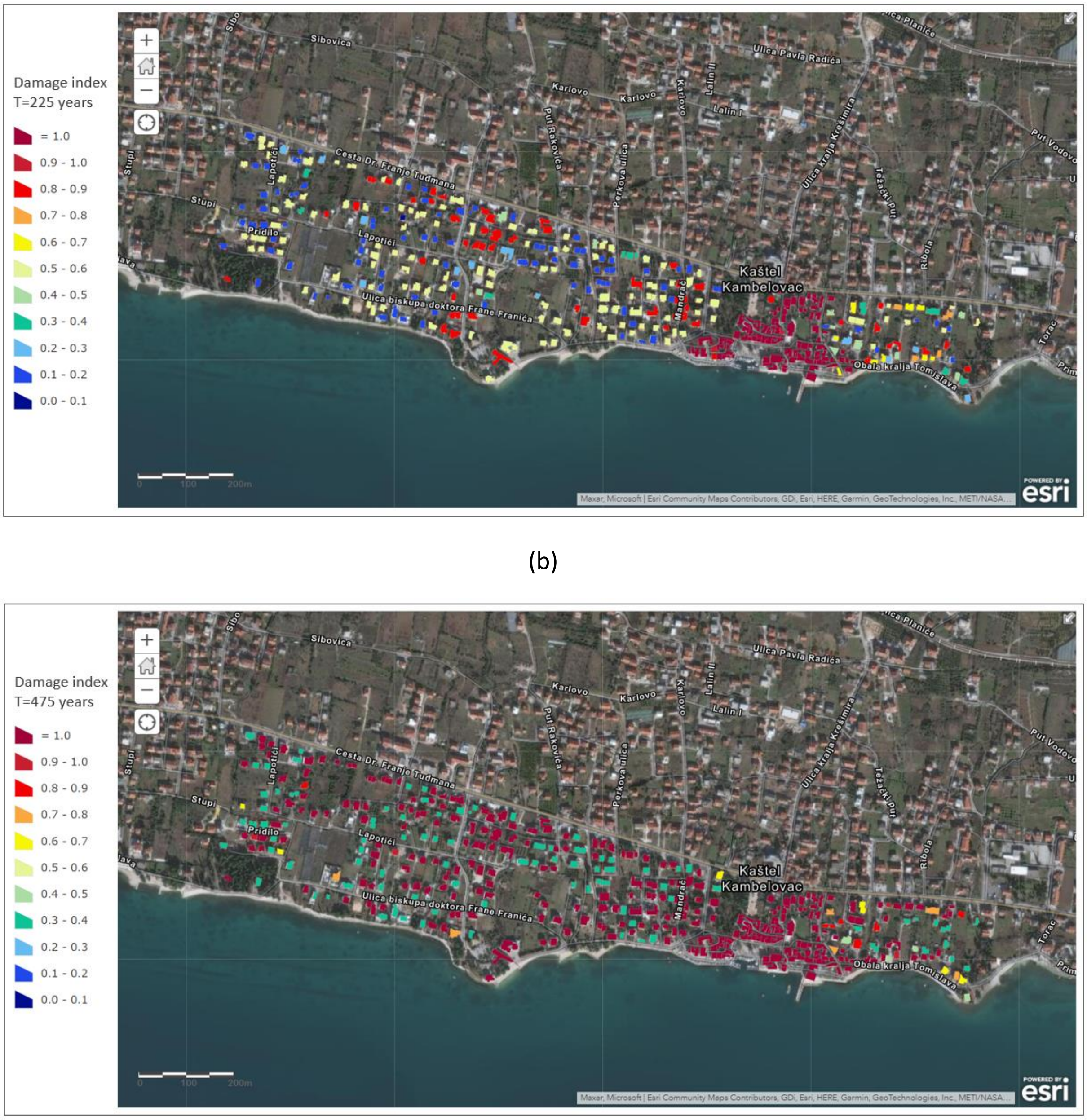
The vulnerability index is not a relevant indicator of seismic risk because it does not give information about the behaviour of the building under a specific seismic action. Seismic risk is represented in terms of damage and index of seismic risk which is an indicator of seismic capacity of the building and depends on collapse peak ground accelerations of the building. The methodologies and procedures for calculation of seismic damage and seismic risk are given in Deliverables 3.3.1 [1] and 3.3.3 [2].

Three seismic scenarios corresponding to return periods 95, 225 and 475 years and demand peak ground accelerations of 0.11g, 0.17g and 0.22g, respectively, have been chosen in this investigations.

The seismic risk in terms of the damage is represented by the damage index maps of the investigated area for given intensity of the earthquake. The damage index is expressed in the 0–1 space by means of a tri-linear law defined by the yield acceleration, PGA_y (damage equal to 0), which represents the beginning of the damage, and the acceleration of the collapse of the building, PGA_c (damage equal to 1). The damage index is used to define spatial distribution of the seismic risk of the buildings in terms of the damage. Damage indexes for the buildings in the test site for three return periods are shown in Figure 8. These indexes are included in the Web map which gives spatial distribution of the damage at the area. In the web map, each building in the area, with a defined cadastral parcel and additional information, is assigned an damage index. The spatial distribution of the damage in the Web map is given in Deliverable 5.1.6 [3].



(a)



(b)

(c)

Fig. 8. Damage index distribution at the test site: (a) T=95 years; (b) T=225 years; (a) T=475 years.

The seismic risk in terms of peak ground acceleration is represented by the index of seismic risk α_{PGA} calculated as a ratio between the collapse peak ground acceleration and the demand ground acceleration for the collapse of the building. Indexes of seismic risk of the buildings for return periods of 95, 225 and 475 years (Fig. 9) have been used to define spatial distribution of the risk in the test site.

These data are included in the Web map. Namely, each building in the test site, with the position, cadastral parcel and additional information, is assigned to index of seismic risk. The maps are given in Deliverable 5.1.6 [3].

(a)

(b)

(c)

Fig. 9. Risk maps in terms of index of seismic risk: (a) T=95 years; (b) T=225 years; (a) T=475 years.

2 Conclusion

This Deliverable presents seismic vulnerability index maps, damage index maps and seismic risk maps for the HR test site Kaštel Kambelovac, Croatian settlement located along the Adriatic coast. The vulnerability indexes, damage indexes and indexes of seismic risks of the buildings at the test site have been calculated according to the methodology and procedure shown in Deliverables 3.3.1 [1] and 3.3.3 [2] of the project. Developed maps indicate different periods of construction of the buildings as well as the specifics of geometry, construction and materials that affect the seismic vulnerability, damage and risk of the buildings. Moreover, spatial distribution of 11 parameters which influence to the seismic vulnerability, damage and risk of the buildings in historical centre is shown and discusses. These parameters evaluate the physical characteristics of the buildings accounting for their structural resistant system, material characteristics, position of the building and foundation, planimetric and elevation configuration, maximum distance between the bearing walls, influence of the roof and non-structural elements and state of conservation (condition). Developed maps represent a basis for the seismic risk management actions.

3 References

[1] Deliverable 3.3.1. Guidelines of the assessment procedure for earthquake vulnerability in HR test site, PMO-GATE project, 2021.

[2] Deliverable 3.3.3. Determination of seismic vulnerability indexes for masonry historical buildings located in the HR test site, PMO-GATE project, 2021.

[3] Deliverable 5.1.6. Map of the spatial distribution of the critical zones most prone to flood, meteo-tsunami and seismic risk in a timely manner to give priority to intervention to authorities and involved parties, PMO-GATE project, 2021.