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# 3.2.2 Definition of the main weak points of the investigated test sites

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## Final Version

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# Summary

# 1. Introduction

## 1.1 Brief presentation of Activity 3.2

Activity 3.2 within Work Package 3 of PMO-GATE project relates to the assessment of flooding in coastal urban areas due to extreme waves exposure. Significant number of objects along the coastline are potentially exposed to flooding due to the impact of extreme waves on the sea surface generated by severe winds. Within this activity, an extreme waves flooding exposure analysis is performed for the particular test site of Kaštel Kambelovac. Furthermore, this activity addresses the main weak points potentially exposed to extreme waves flooding, which in combination with extreme waves exposure maps are used for flood risk assessment on the particular test site. In addition, existing flood risk management plans are evaluated along with the relevant EU legislation. Finally, a set of actions is defined in order to harmonize local flood risk management plans with EU requirements.

## 1.2 Description of the test site – Kaštel Kambelovac

Along the Croatian coast, flooding endangers many low-lying coastal areas potentially exposing significant number of objects to flood hazard. Many historical buildings and/or areas are located along the coastline, which are potentially endangered by coastal flooding as well and subject to significant consequences and damage. The City of Kaštela area is endangered by sea flooding due to its low-lying topography and significant number of cultural and household objects located near the coastline. The particular test site in PMO-GATE project is Kaštel Kambelovac, one of the seven settlements that form the City of Kaštela. This area covers around 45000 square meters and includes more than 400 objects.

The benefit of the chosen area reflects through diversity of objects considering construction, architecture and material, built from the 15th century until today. According to Marasović [1] the oldest objects in the area date back to 1467. These buildings were made of stone with a wooden floor construction, and they remained preserved until today with minor modifications over the years. Historical part of the Kaštel Kambelovac is founded in the 16th century around the Tower of Cambi, as well as the church of St. Mihovil and Martin from the 19th century with a bell tower from 1860. This particular area is a mixture of private and public facilities, mostly built as masonry and concrete buildings. Plan view of the selected area is shown in Figure 1, where the green line defines the border of the test site, purple one defines the border of historical part, while the red line shows position of the natural coastline.

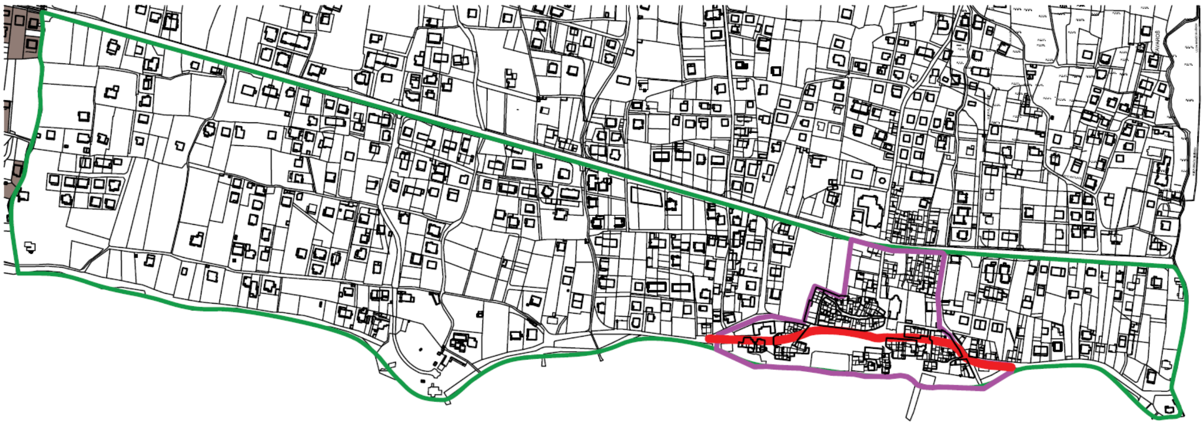

Figure 1. Plan view of the selected area (green line) with the mark of the natural coastline (red line) and the historical part (purple line)

Coastal flooding is considered one of the major threats for coastal urban areas. This is especially related to low-lying coastal areas such as City of Kaštela, where significant part of the city is located near the coastline. High population density in the coastal area of City of Kaštela, together with a large number of buildings and other assets makes this area highly vulnerable. Coastal flooding in the City of Kaštela is becoming more frequent and recent events caused damage to different assets, exposing the weak points within buildings and existing infrastructure.

## 2. Methodological approach for vulnerability analysis

Weak points are defined as the most sensitive locations and their identification depends on the particular scope of the analysis. The identification of these weak points is performed based on the calculation of their vulnerability index. This index reflects their vulnerability through quantification of potential damage objects can suffer if being exposed to some hazardous event. The damage to buildings manifests through physical or structural damage often compromised by age and condition, which are susceptible to decay and damage as a result of moisture ingress. Although the coastal flooding can manifest either from sea level rise or extreme waves, the assessment of these particular components is performed for flood exposure and extreme waves exposure separately. This is due to the fact that these to hazards have different physical properties causing different impact on exposed objects.

The accent of the analysis is on objects in the low-lying susceptibility zones near the coast, which are quantified through their building characteristics, but also through their importance to community. For that reason, we have proposed an approach for vulnerability analysis of potentially exposed objects to flood. The methodology is based on the research of Miranda and Ferreira [2], where they have developed a methodology for flood vulnerability index assessment based on the estimation of two major aspects: exposure parameters and sensitivity parameters. The vulnerability of particular objects to flooding is calculated based on the vulnerability index form (Figure 2), which consists of sensitivity and exposure parameters. Through the quantification process, each of these parameters is assigned with a certain grade in a range for 10 to 100, reflecting the best and the worst state of each particular parameter. The overall vulnerability is based on the total estimated score summarized from all parameter grades.

The sensitivity parameters of the flood vulnerability index are related to building material, overall object condition, number of storeys, building age, and importance of exposed objects. Building material, as the first sensitivity component, directly reflects the building characteristics through structural resistance of object if being exposed to water. We have divided building material into four components, depending on the type of building material used at the observed test site.

The first type is reinforced concrete (RC), which is considered the strongest building material available at the test site, is given a grade 10, followed by masonry structures with confinement with grade

40. Furthermore, masonry structures with well-organized regular blocks and good quality mortar are given grade 70, and masonry structures with poorly organized irregular stones and poor-quality mortar are given 100, making them the weakest building material.

**SENSITIVITY COMPONENT PARAMETERS (SC)**

1. MATERIAL
- ○ A - RC structures (10)
- ◉ B - Masonry structures with confinement (40)
- ○ C - Masonry structures - regular blocks, good organized, good quality mortar; unreinforced concrete (70)
- ○ D - Masonry structures - irregular stone, poorly organized, poor quality mortar (100)

2. CONDITION
- ○ A - No damage, no cracking (10)
- ◉ B - Slight cracking, moisuture (40)
- ○ C - General cracking, settlements, deformations (70)
- ○ D - Exsessive cracking and serious material decay (100)

3. NUMBER OF STOREYS
- ○ A - 3 storey and more (10)
- ◉ B - 2 storey (40)
- ○ C - 1 storey (70)
- ○ D - Existance of basement (100)

4. AGE
- ○ A - 21th century (10)
- ◉ B - 20th century (40)
- ○ C - From 15th to 19th century (70)
- ○ D - Until the 14th century (100)

5. IMPORTANCE CLASS
- ○ A - Buildings of minor importance (10)
- ○ B - Ordinary buldings (40)
- ◉ C - Public buildings (70)
- ○ D - Buildings of vital importance (for civil protection or heritage) (100)

**EXPOSURE COMPONENT PARAMETER (EC)**

6. BUILDING ORIENTATION IN RELATION TO INCOMING WAVE
- ○ A - Angled orientation without openings - 10)
- ○ B - Angled orientation with openings (40)
- ○ C - Frontal orientation without openings (70)
- ◉ D - Frontal orientation with openings (100)

Figure 2. An extract from extreme waves vulnerability index form

The second sensitivity parameter is related to overall building condition. If the building has no visible damage and no cracking, it is considered in a good state and given a grade 10. Presence of slight cracking and moisture reflects the beginning of some deterioration and it is assigned with a grade 40. General cracking and visible deformations on object are quantified with a grade 70, while excessive cracking and serious material decay is quantified with a grade of 100.

Number of storeys are another sensitivity parameter that reflects the vulnerability of object through potential inability of usage and structural vulnerability. Objects with 3 storeys are considered least vulnerable (grade 10) due to the fact that the overall weight of an object is significantly large when it comes to possible movement of an object due to buoyancy or other effects. Furthermore, a 3-storey object is less likely to be total exposed to flooding making most of the storey generally usable. Objects with 2 storeys are considered slightly more vulnerable in comparison to the previous one, and they are given a grade of 40. Objects with only one storey are considered highly vulnerable due to fact that the exposure to flooding can cause total usage inability and impact their overall stability. Object containing basements are considered the most vulnerable due to the fact that water of any intensity will penetrate into basement making it impossible to use, and by the time the water floods the first storey, the whole basement is filled with water causing an overall stability issue.

Building age is considered as another sensitivity parameter. Buildings built in the 21$^{st}$ century are considered least vulnerable duo the building materials used and building regulations applied in the design of objects (grade 10). Buildings built in the 20$^{th}$ century are considered slightly more vulnerable due to weaker building materials and regulations, especially at the beginning of the century. Objects that were built from 15$^{th}$ to 19$^{th}$ century are considered vulnerable, and they are given a grade of 70. Finally, objects that were built until the 14$^{th}$ century are considered the highest vulnerable with a grade of 100.

Importance of objects that exist on the engendered area is considered as a sensitivity issue due to the importance of these objects to community. Objects with no special importance are considered least vulnerable, ordinary buildings are considered more vulnerable than previous ones (grade 40), while public buildings (grade 70) and objects with vital importance are considered highly vulnerable.

The exposure parameter is expressed in relation to building orientation to an incoming wave. The waves are characterized with a significant hydrodynamic force and object orientation is vital due to its capacity to resist and to break the force of an incoming wave. Buildings that have angled orientation to incoming wave and have no openings are considered the least vulnerable to waves because the wave force can break on the angle of object and no water can penetrate into the object. Object with angled orientation with openings are considered more vulnerable as water can penetrate into the object although wave force has been decreased. Objects with frontal orientation to incoming waves are considered more vulnerable due to the fact that waves force is transferred to an object vertically at a right angle which is critical for any object. Furthermore, objects with frontal orientation and openings are considered the most vulnerable not only because of the waves force impact but also due to the fact that the incoming wave is likely to penetrate into the object.

# 3. Identification of main weak points for Kaštel Kambelovac test site

Due to coastal flooding, it is expected that in the test site of Kaštel Kambelovac historical masonry buildings within historical part can be damaged along with other objects and property. So the purpose of this analysis is to recognize the most endangered objects and to identify main weak points based on the flood extend shown in Figure 3. Historical objects in Kaštel Kambelovac, recorded in the Register of Cultural Heritage in Croatia, are listed below are presented:

1. St. Mihovil and Martin Church
2. Tower and Mansion Cambi
3. Historical Oil Mill Cambi
4. Historical urban area of Kaštel Kambelovac
5. Former Ballet School (Music School today)

Considering the second part of the classification, there are few objects with public and other special purpose in Kaštel Kambelovac test site, and they are mostly located in vicinity to coast:

1. City library
2. Rowing club
3. Kindergarten ''Kaštela''
4. Kindergarten ''Smokvica''

Besides historical and public objects, the rest is mostly related to household and residential objects. Regarding these buildings, it is expected that objects near the coastal line and more sensitive to flooding. However, compared to protected households in the historical area, it is common to expect that recently built objects have higher adaptive capacity and the possibility to adjust to changing conditions. Regarding the identified endangered infrastructure, there is no record on significant infrastructure on the particular test site, only a local road placed along the coastal line of test site.


Figure 3. Flood extend in relation to exposed objects

## 4. Extreme waves vulnerability index results for Kaštela test site

Table 1. Extreme waves vulnerability indexes for exposed objects

| Label | Building name or address / Construction period | Photo | Building position | Vulnerability index $I_v$ |
|---|---|---|---|---|
| 1.1 | Kula Kambi<br>XV century |  |  | 82 |
| 1.2 | Polantana 5<br>XIX century |  |  | 46 |
| 1.3 | Brce 18<br>XIX century |  |  | 40 |
| 1.4 | Cambijev trg 18<br>XIX century |  |  | 40 |
| 1.5 | Polantana 8, 11<br>XVIII century |  |  | 40 |

| | | | | |
|---|---|---|---|---|
| 1.6 | Polantana 12<br>XVIII century |  |  | 46 |
| 2.5 | Trg Didića 4<br>XVIII century |  |  | 46 |
| 2.6 | Trg Didića 3<br>XIX century |  |  | 40 |
| 2.7 | Stipe Gančevića 8<br>XVIII century |  |  | 64 |
| 2.8 | Stipe Gančevića 10<br>XIX century |  |  | 64 |
| 2.9 | Cambijev trg 11<br>XIX century |  |  | 58 |
| 4.1 | Trg Didića 8<br>XIX century |  |  | 16 |

| | | | | |
|---|---|---|---|---|
| 4.3 | Obala Didića 10, 11, 12, 13, 14<br>XIX century |  |  | 40 |
| 4.4 | Kindergarten<br>XIX century |  |  | 64 |
| 4.5 | Rowing club<br>XX century |  |  | 58 |
| 5.1 | Library<br>XIX century |  |  | 64 |
| 5.2 | Perišin<br>XIX century |  |  | 40 |
| 5.3 | Pučki kaštel<br>XIX century |  |  | 40 |
| 5.4 | Polantana 2<br>XIX century |  |  | 40 |

| | | | | |
|---|---|---|---|---|
| 5.5 | Polantana 3, 4<br>XIX century |  |  | 40 |
| 5.6 | Brce 20<br>XIX century |  |  | 46 |
| 5.7 | Brce 25<br>XIX century |  |  | 46 |
| 8.5 | Brce 13, 14<br>XIX century |  |  | 16 |
| 8.6 | Brce 11, 12<br>XIX century |  |  | 16 |
| 8.7 | Brce 9, 10<br>XX century |  |  | 16 |
| 8.8 | Brce 8<br>XX century |  |  | 14 |

| | | | | |
|---|---|---|---|---|
| 8.11 | Brce 7<br>XX century |  |  | 14 |
| 8.12 | Brce 6<br>XIX century |  |  | 18 |
| 8.13 | Brce 5<br>XIX century |  |  | 21 |
| 9.4 | Brce 1, 2<br>XVIII century |  |  | 40 |
| 9.5 | Brce 3<br>XIX century |  |  | 52 |
| 9.9 | Ribarski prolaz 5<br>XIX century |  |  | 21 |

# References

[1] Marasović K.; Kaštelanski zbornik, 7, 35-61, 2003.g.

[2] Miranda, F.N., Ferreira, T. M., A simplified approach for flood vulnerability assessment of historic sites, Natural Hazards (2019) 96:713–730, https://doi.org/10.1007/s11069-018-03565-1