Received: 07.08.2023.
Accepted: 05.10.2023.

e-ZBORNIK Special Issue

Professional paper

Electronic collection of papers of the Faculty of Civil Engineering

https://doi.org/10.47960/2232-9080.2023.SI.13.129 ISSN 2232-9080

Diagnostics of the condition of the Tabija tower in Mostar

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Abstract: Based on measurements and research, diagnostics of the condition of a structure aims to provide an answer to the question of what the condition of the structure is, and the necessary steps for reconstruction or rehabilitation. Masonry stone construction is one of the oldest methods of construction of building structures. In spite of that, this type of structures does not have fully defined parameters that influence its behavior. The reason for this is the fact that the properties of masonry stone structures differ depending on the basic material (stone) and binding material (mortar), as well as their combination. The paper presents diagnostics of the condition of masonry structures on the Tabija tower building. Tabija, a low tower for cannons, is a fortification structure from the Ottoman period that is the most completely preserved and was registered for the first time in the city plan from 1717. The structure is in poor condition due to a large number of natural and human factors. The paper will present a detailed visual inspection of the structure, as well as tests conducted in the laboratory and in-situ, the calculation, and decisions and proposals for the rehabilitation and/or reconstruction of the considered building of cultural and historical heritage.

Key words: diagnostics, stone, rehabilitation, durability

Dijagnostika stanja kule Tabija u Mostaru

Sažetak: Dijagnostika stanja konstrukcije ima za cilj na temelju mjerenja i istraživanja dati odgovor na pitanje u kakvom je stanju konstrukcija, te neophodne korake za rekonstrukciju ili sanaciju. Zidane kamene konstrukcije su jedan od najstarijih načina izgradnje građevinskih objekata. Usprkos tome, ovaj tip konstrukcija nema u potpunosti definirane parametre koji utiču na njeno ponašanje. Uzrok ovome je činjenica, da se osobine zidanih kamenih konstrukcija razlikuju u zavisnosti od osnovnog materijala (kamena) i vezivnog materijala (maltera), te njihove sprege. U radu je prikazana dijagnostiku stanja zidanih konstrukcija na objektu kula Tabija. Tabija, niska kula za topove, je fortifikacijski objekt iz osmanskog perioda koja je najcjelovitije očuvan i po prvi put je evidentiran u planu grada iz 1717. godine. Objekt je zbog velikog broja prirodnih i ljudskih faktora u lošem stanju. Rad će prikazati detaljan vizualni pregled objekta, te provedena ispitivanja u laboratoriji i in-situ, proračun, te odluke i prijedlozi za sanaciju i/ili rekonstrukciju razmatranog objekta kulturno-povijesnog naslijeđa.

Ključne riječi: dijagnostika, kamen, sanacija, trajnost

1. INTRODUCTION

Cultural assets are often compared to living beings. Discussions about conservation and restoration works involve the terms such as diagnosis, therapy, and treatment. Just as ecology deals with the study of the relationship between living beings and their environment, so can a new scientific discipline be discussed, being in fact a synthesis of several scientific disciplines, whose area of interest is the relationship between a cultural asset and its environment (Puljić and Krač, 2014).

The diagnostics of the condition of a structure, as a key activity in the process of durability and maintenance of the structure, provides an answer to the question of what the condition of the structure is (Čaušević and Rustempašić, 2014). In this respect, an excellent parallel can be made with the diagnostics of the human condition. Just as a systematic examination is a cross-section of the current health condition for an individual, so diagnostics of the existing condition is the same for an existing structure. In order to get an evaluation of our present condition, we must have laboratory tests done, be visually examined by a specialist, undergo tests with sophisticated equipment, etc., and based on the scrutiny of all findings and detailed examinations by a specialist, we are provided with an answer about our health condition and whether we need an intervention (surgical, medication, lifestyle change, etc.)

In a very similar way, the diagnostics of the condition of an existing structure can be divided into:

- collection of documentation (collection or reconstruction of drawings, collection or reconstruction of calculations)
- inspections and tests of the structure (inspections, tests and monitoring of the structure)
- calculation and decision on further action (calculations, assessments and decision on further action), (Zlomušica et al., 2020).

A large number of practical problems with masonry structures in building construction are encountered every day. There is a tremendously large number of war-damaged or completely destroyed masonry buildings, which belongs to the group of deliberate demolitions of structures. The devastation of these buildings is deepened and accelerated by the aggressive effect of elements. After wartime destruction, masonry structures were exposed to decay for a long period of time, due to the effects of atmospheric agents as an additional cause of their destruction (Šahinagić-Isović et al., 2018). The causes of the deterioration of masonry structures from this group are: changes in temperature, moisture, as well as wind and pollution. The necessary intervention on a structure is defined by a set of investigation works and testing activities.

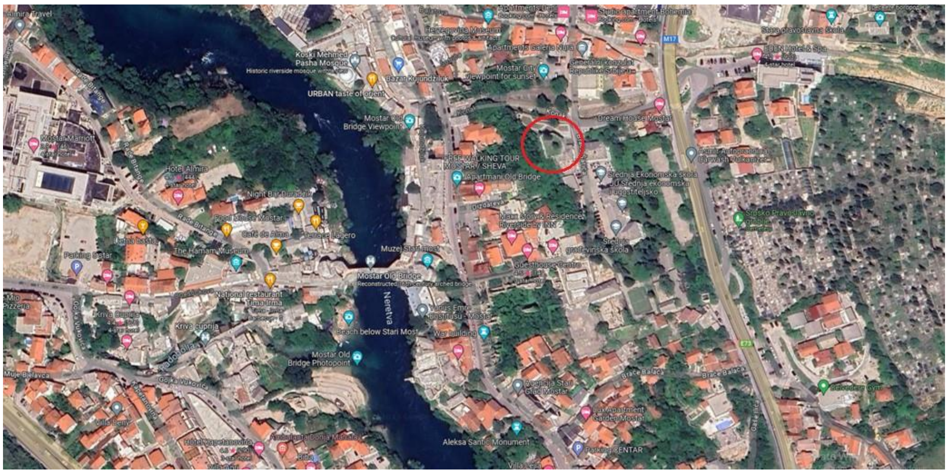

Figure 1. Tabija tower site, (Kukrica, 2022)

Very often, data on the original design and calculation of the structure, or drawings of the as-built state, are not available. Original data on the masonry structure of the Tabija tower have not been found. In this case, the methods of diagnostics of the state of the structure are used to determine the dimensions of sections, the geometry of the structure, the parameters that describe the properties of the materials from which the individual structural elements are made, and the like. Tabija, a low tower for cannons, is a fortification structure from the Ottoman period that is the most completely preserved, and was registered for the first time on a veduta and city plan from 1717. The environmental and historical concept of the Tabija tower has been preserved thanks to its being located in an area where there are no newer buildings that clash too much with the context itself with their structure and characteristics. The structure is situated in the central core of the city, in the immediate vicinity of the Old Bridge, a UNESCO World Heritage Site (Figure 1).

No significant conservation or reconstruction repairs were done on the tower. The causes of this neglect are the lack of finances and the exclusion of historical heritage from urban planning. An important step in the diagnostics of the condition of the existing structure includes site visits and visual inspection of the structure.

2. INSPECTIONS OF THE STRUCTURE

In the diagnostics of the condition of the existing structure, the step following the analysis of the available documentation on the observed structure (if any) includes site visits and visual inspection of the structure. A visual inspection of the structure determines damage to individual structural elements, its causes, extent, and the impact on the bearing capacity and usability of that element and the structure as a whole. During the inspection of the structure, special attention should be paid to:

- geometry and measurements of sections,
- appearance and differences in the color of the structure's surface,
- occurrence of cracks, their size and distribution,
- signs of material degradation on the surface of the structure,
- structural deformations,
- wet surfaces or places of water leakage, (Radić, 2010)

Drawings of the current condition of the wall structure of the Tabija tower were made through visual inspections of the geometry and measurements. Figures 2, 3 and 4 show parts of the walls of Tabija through drawings, which are accompanied by corresponding photographs. (Kukrica, 2022).

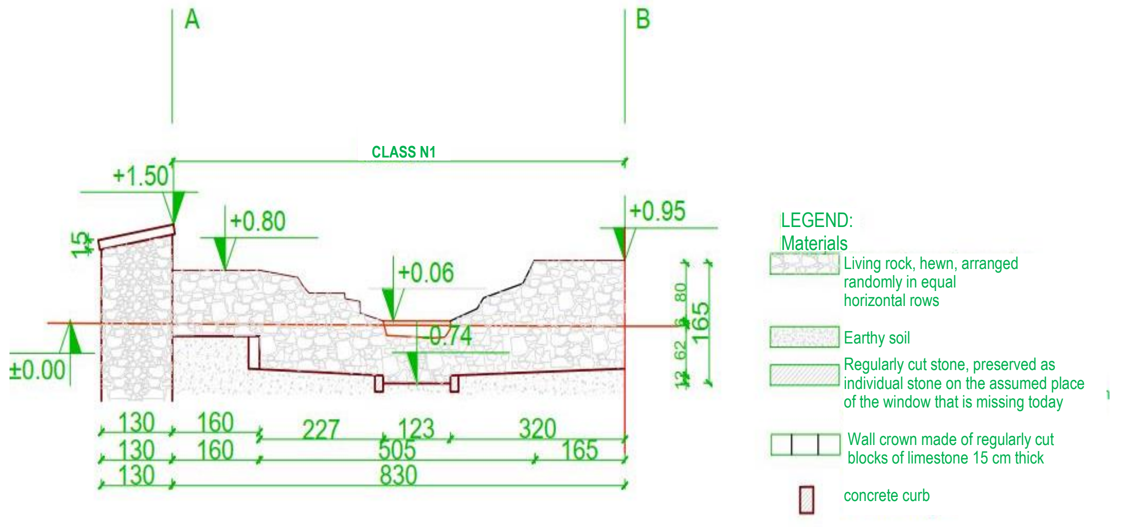

Figure 2. Sketch and photo of internal wall AB, (Kukrica, 2022)

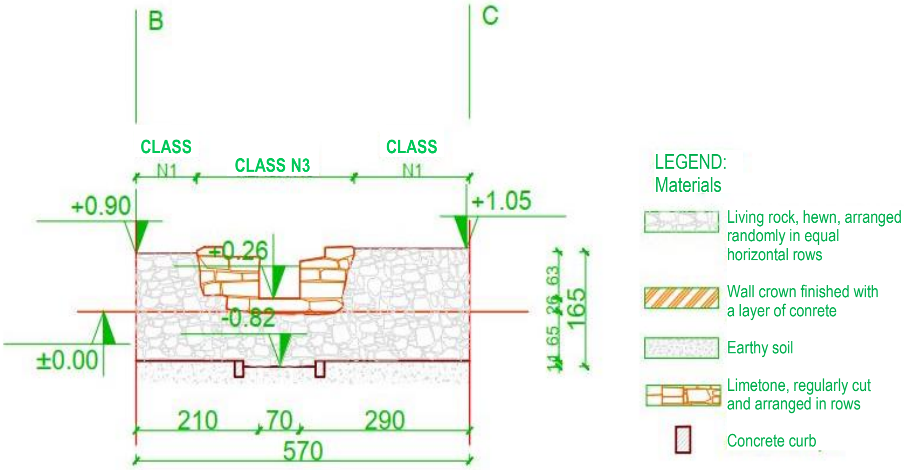

Figure 3. Sketch and photo of internal wall BC, (Kukrica, 2022)

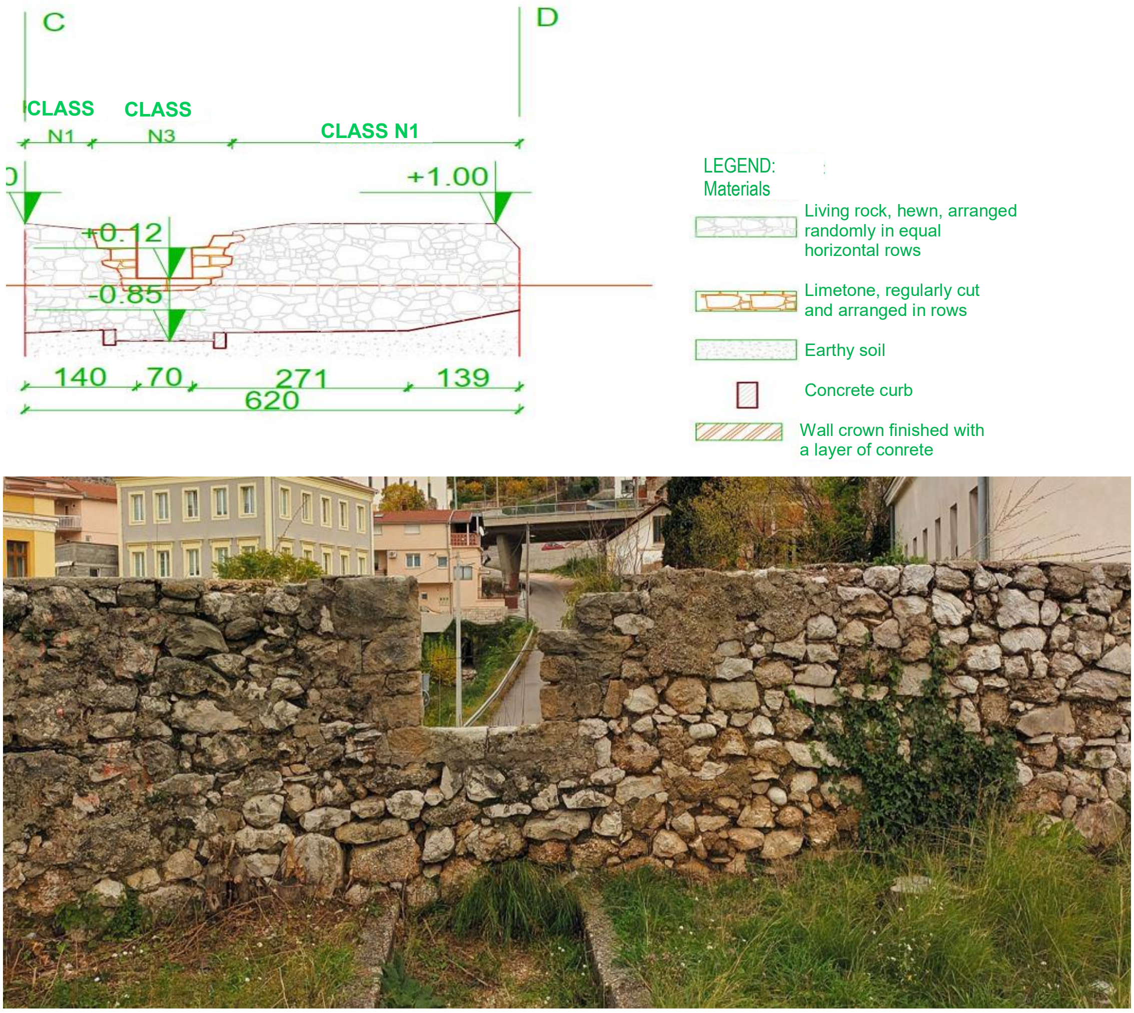

Figure 4. Sketch and photo of internal wall CD, (Kukrica, 2022)

The visual inspection of the studied structure identified the following defects and damage (Kukrica, 2022):

- damage caused by biological action
- separation of mortar
- absence of concrete cap
- cracks
- peeling/separation of stone parts
- graffiti / human impact on the structure.

2.1 Vegetation

Biological action has substantially damaged the durability of the Tabija tower. Vegetation covering a large part of the walls, especially on the outside, has appeared due to long-term neglect. Vegetation has also caused the wall to crack and the mortar to break, some parts of the wall to collapse during the extraction of the same, the beams to lift (the roots of wild plants in this area are quite strong and difficult to clear). We distinguish between vegetation that we can control and that which we cannot control due to the inaccessibility of the terrain. Vegetation has caused the following (Figure 5 and 6):

Figure 5. The outer surface of the wall covered with vegetation and its condition after its removal

Figure 6. Damage caused by root action

2.2 Separation of mortar

When constructing a wall or renovating a building, the necessary conditions should be provided so that the mortar does not lose water, which is necessary for proper binding and hardening of the binding agent, because the impossibility of further hardening and the loss of adhesion of the mortar to the wall element occur as a result. In the process of conservation, the structure was repaired with cement mortar on several occasions in the past, in which process it was not properly pointed and, as evident in the figure (Figure 7), the mortar separated.

Figure 7. Separation of mortar

2.3 Absence of concrete cap

The concrete cap is destroyed in several places due to washing or the action of vegetation during the past years (Figure 8).

Figure 8. Absence of concrete cap

2.4 Peeling/separation of stone parts caused by freezing and thawing processes

As the tower is a completely exposed structure, both the internal and external walls are constantly under climate effects. The climate of Mostar in winter is quite distinct, with low temperatures and heavy precipitation, so that the structure itself has been subjected to the effects of wind and rain over the years. The absence of a concrete cap in several places makes it easier for the wind to have a more pronounced effect on the structure and on the peeling of the stone (Figure 9).

Figure 9. Stone separation

2.5 Human influence on the structure

The immediate surroundings of Tabija are used for waste disposal, its walls are often a surface for graffiti, and access points for parking (Figure 10).

Figure 10. Graffiti on the structure

3. LABORATORY TESTS

Non-destructive and destructive testing methods, conducted at the location of the structure or in the laboratory, are used for the purpose of diagnosing the condition of structures. Tests performed on samples are:

- testing compressive strength in the natural state,

- testing compressive strength in a water-saturated state,
- testing bending strength in the dry state,
- testing bending strength in a water-saturated state,
- testing bulk density with pores and cavities,
- testing water absorption,
- testing porosity.

Dimension stone is used in construction as a masonry element. Stone as the basic dimension material has been used in Herzegovina from Roman times, to the Turkish and Austro-Hungarian periods to the present day. The stone used in most structures is from the Mukoša quarry south of Mostar. At that site, there are limestones: fine-grained porous limestone "miljevina" and ooliolitic limestone "tenelija".

Tenelija has proven to be a stone that is easy to cut and dress; just extracted from the quarry while still containing quarry moisture, it can be cut with an ordinary hand saw and dressed with the simplest tools. For this reason, it was often used as a material for decorative parts of buildings, frames and arches, columns with decorated capitals, and tombstones. These two types of stone, tenelija and miljevina, both are good raw materials for the production of dimension stone because they are slightly degraded by cracks and fissures. The two stones are intercalated in the deposit, i.e. they alternate with each other as interbeds and are very difficult to separate in the field, although generally speaking, tenelija makes up the upper rock layer that follows the configuration of the terrain in layers 60 cm to 2 m thick. After that, a sharp transition to the fine-grained limestone of the lower layer - miljevina - is clearly visible.

Tenelija is a stone with a yellowish color when it is just extracted from the quarry and a light brown color in the wet state. When dried, it acquires a whitish color, and with time and aging, a light gray and gray color. It has a homogeneous texture and high porosity. Miljevina is a whitish to yellowish stone with darker brown-yellowish microlayers. It is light brown when wet. Unhealed millimeter pores can be observed in some places on the sawn surface, which is markedly smooth. It has an uneven fracture, and the fracture edges are worn. It has permanent high moisture and is difficult to dry.

According to the categorizations of dimension stone, tenelija and miljevina are classified as stones of very low strength, medium heavy, extremely porous and with high water absorption. The compressive strength of tenelija ranges between 25 and 45 MPa, and of miljevina between 15 and 30 MPa. Tenelija and miljevina alternate in interbeds and in many locations in the rock mass it is not possible to extract usable blocks of dimension stone, either tenelija or miljevina (Bilopavlović et al., 2013). In addition to low compressive strength, unfavorable properties that should be taken into account are high water absorption and lack of resistance to wear. According to the result of the wear resistance test, tenelija is classified as an extremely soft stone, which in a built-in structure means a tendency to mechanical wear, rounding of sharp edges, etc. High water absorption has a direct impact on frost resistance and reduced compressive strength in wet conditions. In tenelija, due to the coarse-grained structure, water drains out faster and stays in the stone structure for a shorter time. For this reason, it is very important to protect the stone also for aesthetic reasons, because it changes color under the influence of atmospheric agents.

The properties and durability of tenelija and miljevina are best evidenced by the stone built-in in buildings from the near and distant past. Table 1 presents the basic properties of tenelija and miljevina (Bilopavlović et al., 2013).

Table 1. Physical and mechanical properties of tenelija and miljevina

Property		Stone	
		Tenelija	Miljevina
Density [g/cm^3]		2.616	2.402
Required mass [g/cm^3]		1.977	1.837
Porosity [%]		24.4	23.6
Water absorption	Under atm. pressure	9.47	14.10
	By cooking in water	14.11	16.30
Saturation coefficient		0.67	0.87
Frost resistance		unresistant	unresistant
Compressive strength [MPa]	In dry state	37.1 (32.9-45.0)	23.0 (20.8-24.7)
	In water-saturated state	30.8 (27.7-36.2)	17.0 (14.0-20.7)
Coefficient of softening		0.83	0.74

4. CALCULATION OF THE STRUCTURE

Before calculating the walls, it is necessary to perform their classification. The classification of the masonry walls was carried out according to the standard DIN EN 1996-1-1. According to the criteria, walls are classified into classes N1 to N4. This classification is important, because it is one of the most important parameters defining the bearing capacity of a masonry structure made of natural stone. The basic classification results from the method of masonry construction, the shape and degree of dressing of stone blocks, while the detailed classification can be determined based on the joint thickness to stone length ratio, inclination of the bed joint and the transfer factor.

Walls made of natural stone can be divided according to different criteria:

1. According to the degree of stone dressing:
   - walls of rough stone,
   - walls of roughly dressed stone,
   - walls of finely dressed stone,
   - walls of ashlar.
2. Depending on the application of binder:
   - walls without binder (dry stone walls),
   - walls with binder (lime, pozzolanic or combination cement mortar).
3. According to the layering of the walls:
   - single layer walls,
   - multi-layered walls.
4. According to the type of wall connection and masonry construction method (according to DIN EN 1996-1-1/NA.L):

   4.1. polygonal wall binding
   - wall of isolated stones
   - cyclopean wall of broken stone (class N1)
   - cyclopean wall (class N1)

   4.2. orthogonal wall binding (according to DIN EN 1991-1-/NA.L.2)
   - wall of broken stone (class N1)
   - wall of dressed/hewn stone, class N2
   - wall of dressed/hewn stone, class N3
   - wall of finely dressed square blocks/cut stones (class N4).

The Tabija tower was built of limestone, namely:

- living rock (natural stone), hewn and arranged randomly in equal horizontal rows and these walls can be assigned mostly to class N1 or N2 by the qualification
- and tenelija stone that is properly hewn and arranged in rows, parts of the tower built in this way belong to class N3.

Table 2 gives a detailed overview of the class of all internal and external walls.

Table 2. Classification of walls of the Tabija tower

	Internal walls						External walls					
Wall	AB	BC	CD	DF	FG	GA	AB	BC	CD	DF	FG	GA
Class of walls	N1	N1 N3	N1 N3	N1	N1 N2	N1 N2 N3	N1 N3	N1	N1	N1	N1	N3

Calculation of the structures is performed globally and locally. Due to the imperfections of the overall geometry of the tower's walls, global calculation was not carried out, and the walls have been in this area for 500 years now, so there is no doubt about the global calculation of the structure. Local calculation of parts of the free-standing wall was carried out. Calculation of parts of the wall in a 1m length was conducted for all three classes of walls (N1, N2 and N3) located in the structure, namely:

As part of the calculation of parts of free-standing walls for the effect of wind (+constant load), the following was performed:

- compressive stress check,
- proof of safety against overturning
- shear capacity check

When calculating parts of free-standing walls for seismic action (+constant load), the following was performed:

- compressive stress check,
- seismic shear capacity check

Tables 3 and 4 present the calculation results for each type of wall class.

Table 3. Calculation results for wind effect

	Class N1, wall AB	Class N2, wall FG	Class N3, wall GA
Compressive stress check,	σ_1 = 77.98 kN/m^2 < f_d = 350 kN/m^2 Degree of utilization: 22.28% σ_2 =39.78 kN/m^2 < f_d = 350 kN/m^2 Degree of utilization: 11.37%	σ_1 = 85.7 kN/m^2 < f_d = 700 kN/m^2 Degree of utilization: 12.24% σ_2 =45.94 kN/m^2 < f_d = 700 kN/m^2 Degree of utilization: 6.6%	σ_1 = 99.09 kN/m^2 < f_d = 825 kN/m^2 Degree of utilization: 6% σ_2 =42.63kN/m^2 < f_d = 825 kN/m^2 Degree of utilization: 5.2%
Proof of safety against overturning	σ_1 = 62.72 kN/m^2 < f_d = 350 kN/m^2 Degree of utilization: 17.92% σ_2 =24.52 kN/m^2 < f_d = 350 kN/m^2 Degree of utilization: 7%	σ_1 = 68,63 kN/m^2 < f_d= 700 kN/m^2 Degree of utilization: 9.8% σ_2 =28.87 kN/m^2 < f_d = 700 kN/m^2 Degree of utilization: 4.12%	σ_1 = 79.31 kN/m^2 < f_d = 825 kN/m^2 Degree of utilization: 9.6% σ_2 =33.60 kN/m^2 < f_d = 825 kN/m^2 Degree of utilization: 4.1%
Shear capacity check	V_{Ed} = 4.5 kN ≤ V_{Rd} = 66kN	V_{Ed} = 5.02 kN ≤ V_{Rd} =96kN	V_{Ed} = 5.8 kN ≤ V_{Rd} =78kN

Table 4. Calculation results for the seismic effect

	Class N1, wall AB	Class N2, wall FG	Class N3, wall GA
Compressive stress check,	σ= 456.95 kN/m² < f_d = 526.32 kN/m² Degree of utilization: 86.81%	σ = 354.54kN/m² < f_d = 1052.63 kN/m² Degree of utilization: 33.68 %	σ = 1223kN/m² < f_d = 1240.60 kN/m² Degree of utilization: 98.58 %
Seismic shear capacity check	V_{Ed} = 13.62 kN ≤ V_{Rd} =31.57 kN	V_{Ed} = 15.1 kN ≤ V_{Rd} =42.18 kN	V_{Ed} = 20.5 kN ≤ V_{Rd} =36.31

5. REHABILITATION MEASURES

Based on the tests and inspection of the structure, it was determined that the approach to the interior of the tower is difficult and unsafe, which is why this part remains unexplored. Before any interventions on the structure itself, with the aim of preserving its appearance and purpose, it is necessary to ensure unobstructed and safe approach to the structure, as well as a structure lighting plan that will allow safe access (Šarančić-Logo et al., 2021; Šahinagić-Isović and Ćećez, 2017).

The interventions that need to be carried out on the structure are:

- It is necessary to remove vegetation that impairs the appearance and function of the structure. The roots that compromise the walls must be permanently removed with permitted biochemical means so that reconstruction of the damaged parts of the wall can be carried out on these parts.
- After carrying out the permanent removal of the roots, it is necessary to decompose the parts of the wall that have been destroyed by vegetation while marking all the stone blocks and then recompose and reconstruct them using material of the same type (stone and mortar, for the mortar use one based on natural hydraulic lime (NHL) intended for historical buildings). On the entire surface of the wall, it is necessary to clean the joints and repoint them using NHL mortar.
- For stone walls, drilling is performed along the passage of the joints. Clean the holes thoroughly with compressed air. Close all joints, cracks and interruptions where the injected mortar could come out.
- When cleaning the wall facades, the missing stone blocks in individual places should be reconstructed using materials of the same type.
- During decomposition, it is also necessary to repair observable cracks. If the stability of the structure is compromised during the repair of the bearing capacity of the concrete surface, it is necessary to connect the sides of the crack to ensure load transfer again. For this purpose, the crack is filled with resin along its entire transverse length.
- The structure is not protected from atmospheric effects and therefore water represents a big problem. Due to the large amount of precipitation during the year, water is highly likely to find its way to the interior of the wall and continue to destroy the structure, if the drainage is not solved. Attention should be paid to developing the plateau so as to make drainages that will collect water in one place and conduct it to the rainwater system.
- During the intervention, the horizontal line of the stone layer is to be retained.

6. RECOMMENDATIONS FOR FURTHER RESEARCH

The shortcomings of the Konak complex are primarily the neglect/dilapidation of the structures and the unpreparedness of the tourist infrastructure, but also in the accompanying facilities from the support production and service activities that can be used for tourism. The attractive location itself, such as the tower complex, is insufficiently developed and marked. The main disadvantages are related to underdeveloped tourist and municipal infrastructure, which requires more time and much resources. Other shortcomings, such as poor promotion or lack of organization of tourist entities, can be solved much faster.

The decision on the protection of the structure should define not only the development of Tabija, but also the development and protection of its surroundings, and up-to-date technical regulations should define the conditions necessary for the use of the structures. It is necessary to provide the safety of the structure, protection from vegetation, lighting, a developed and illuminated road to Tabija, increase promotion in terms of erecting a board, solving the issue of garbage disposal, ensuring the usability of the structure for a specific purpose, and the like.

The tower itself has completely retained its authentic form and materials, so any work that could be undertaken to save this tower damages its authenticity to a greater or lesser extent and it could lose the original value to some extent.

According to the spatial possibilities of Tabija, it is not possible to make major changes, nor does it have a great economic potential. Consequently, we can say that there are problems adapting the historical structure to modern conditions, that is, the functional scheme of the structure does not meet modern needs.

Tabija has therefore lost its authentic purpose, so in this case, when it comes to a structure whose purpose has ceased, or has been overcome by the contemporary way of life, it is necessary to give the structure a new purpose. According to the above, revitalization is much needed in order to realize the conversion of this historical structure for new purposes within the limits and in a way that would ensure the preservation of the nature, character, significance and monumental values of the structures and the historical environment.

From the conservation aspect, the goal of the project is not only to make the structure "fit" for a new purpose through technical interventions: by introducing the necessary installations and carrying out rehabilitation work. The ensemble needs to be revitalized - returned to an active urban fabric, through the presentation of its architectural, historical and typological values: by animating and letting visitors into all its parts, and allowing free movement through the Konak complex.

It is proposed to restore the tower with the connecting part of the walls, while adapting the complex into spaces intended for exhibition and museum displays, organization of promotions, lectures, workshops, video showings, galleries and placing a cafeteria within the lookout.

Tabija, as part of Konak built by Ali Pasha Rizvanbegović in the middle of the 19th century, could now be presented as an improved lookout with panoramic binoculars, benches, and a replica of a cannon that would bring the experience of this historically significant cannon tower closer. Since the entire Konak system consists of towers, gates, walls, independent fortifications and military accommodation facilities, changing their purpose could increase the economic potential. In that case, the plateau should be arranged as a park, with furniture for rest, while the space at the place of the guardhouse would be suitable for a tourist information desk, a kiosk or a public toilet.

The implementation of the given activities, the project for the renovation and reconstruction of Konak and the Tabija tower, would create the economic potential of this location, increase the number of tourists, and increase the business in trade, tourism and catering.

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