Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

ASSESSMENT, EVUALATIONS AND RETROFITING APPLICATIONS METHODS FOR MASONARY OLD STONE STRUCTURE

Naser Kabashi [(1)], Enes Krasniqi [(2)], Teuta Imeri[(3)],Ylli Murati[(4)], Alush Shala[(5)]

[(1)] *Prof.dr, University of Prishtina, naser.kabashi@uni-pr.edu*
[(2)] *Teaching Assistent, University of Prishtina, enes.krasniqi@uni-pr.edu*
[(4)]*Teaching Assistent, University of Prishtina, ylli.murati@uni-pr.edu*
[(3)]*Alb-Architect Company, Prishtina, teutaimeri@albarchitect.com*
[(5)]*Alb-Architect Company, Prishtina, alushshala@albarchitect.com*

Abstract

The deterioration of old masonry structures, particularly from the Middle Ages, poses significant challenges due to material degradation and structural deficiencies. This study focuses on assessing and strengthening a traditional stone masonry "Kulla," addressing the need to preserve its historical character while improving its structural performance to meet modern building codes. The research objectives are to identify material and structural deficiencies, evaluate the impact on load-bearing capacity, and develop effective retrofitting techniques. A combination of non-destructive and destructive testing methods was used to analyze material properties and structural elements such as stone foundations, walls, roofs, and floors. The results revealed substantial material deterioration, particularly in the stone masonry, leading to the design of a tailored retrofitting strategy focused on strengthening key elements. This retrofitting approach significantly improves the building's seismic and structural resilience, with comparisons showing a marked improvement between the building's current and retrofitted conditions. The study highlights the importance of integrating material analysis and retrofitting techniques to preserve the structural integrity and historical value of ancient masonry structures in seismic regions.

Keywords: Masonry structures, Retrofitting, Material testing, Seismic resilience, Historical preservation

1. Introduction

Historical buildings are an important part of the cultural heritage, because of their architectural value, materials and techniques of building in different years or eras. Their conservation over the centuries is a responsibility of our society, in order to pass on to future generations. The diagnosis of the present conditions of the building can be made by a complete interdisciplinary knowledge based on historical notes, technological survey, non-destructive testing, destructive testing, procedures and the interpretation of crack and decay patterns. Slow and inevitable aging processes might affect the current structural stability due to different possible origins. In this concept more effected factors are the materials deterioration in scope of time and environmental effects.[1].

In different buildings one or more of threes parameters will lead to the damages in buildings in slowly time effect, which are under the Institutions for evaluations the Cultural Heritage Buildings:

- behavior the buildings under natural hazards (floods, earthquake, fire,etc). The seismic assessment of existing buildings is a complex task, basically for two different reasons:
- the difficulty of interpreting and modelling the seismic response; and
- the difficulty of acquiring as-built information on material parameters and structural details, due to their spatial variability in the buildings and the need of avoiding invasive testing.

A detailed assessment through proper procedures and models allows to avoid collapse and useless interventions. The analyses need to involve more different knowledge in different specific fields.

Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

2. Architectural and structural assessment of existing Cultural Heritage Buildings

Architectural and structural assessment of Cultural Heritage Buildings is a crucial process that preserves, restore and maintenance the structures, more focused in specific important buildings which represent the autochthony of country and populations. The assessment involves several stages, for better understanding the building's current conditions, historical importance and the measurements to ensure its durability of structures.[1].

2.1. The origin and establishment of the survey concept

During the analyzing the survey concept and eventually intervention on the Cultural Heritage Buildings, it is essentially to analyses the documents for current conditions of the structural components stability and state of the materials actually in buildings. The documents should explain the specific reasons for selections the materials and methods in preservation efforts. The rational approach for the survey stage must keep guided by the following general principles:

- Each traditional building has different and singular aspects that make them unique, leading to slightly different survey needs, from case to case.
- The selection of the means of inspection, appraisal and recording must be adaptable to the nature of the building, physical and in situ limitation of survey actions and available resources;
- The survey actions should be based on the general scope and most important and critical aims of the project. Any repair, maintenance, refurbishment action or intervention strategy should reflect the technical and financial effort made in the survey phase;
- The survey is a multidisciplinary task, including the surveyor teams (engineers, architects, historians, archaeologists, etc.) with expertise opinion is very valuable.
- The use of other sources of information, such as the documentary information is
- Also, very valuable and should be considered.

The establishment of survey concept in case Study: Kulla e Ymer Poges, is result of:

- Geometric measurements (using a laser scanner and direct measurements)
- Site visits and direct observation of the monument's condition
- Interviews with local residents (who provided insights into the monument's functional history)
- Photographs and videos

2.2. Functionality of Cultural Heritage Buildings –Case Study Kulla-Ymer Poga

The analyzing building is type of traditional residence of tower type, characterized with plane dimensions 6.35 x 6.35 m and three stories high. The primary function of the building was residential, with the ground floor serving as a stable, the first floor designated for the residents of the house, while the second floor housed the guest room. For a period, the tower is said to have served as a mosque. This is evidenced by the dome found in the guest room, making the tower unique in construction style in Kosovo and beyond.[2]. The entrance to the tower was made through two doors: one located on the ground floor used by family members, and the other, now walled up, located again on the northeast side on the second floor of the tower, used for guest entry. This door is thought to have been accessed via movable external stairs. Detail of the ground floor, first floor and second floor are presented in figure 1.

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

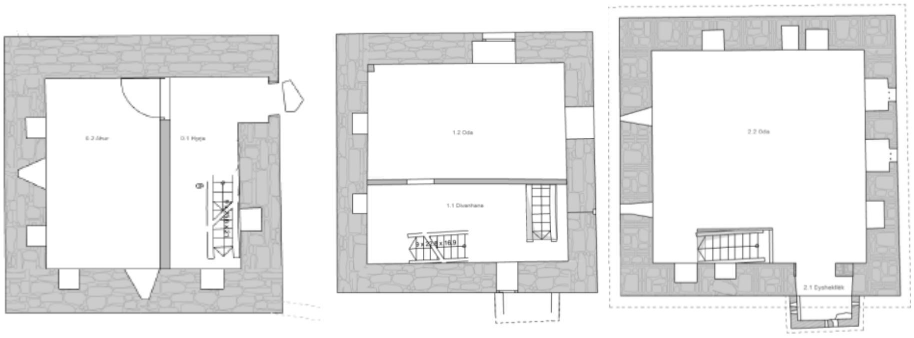


Figure 1. Three floors space of Kulla- Ymer Poga

2.3. Interventions over the Years on the building

Comparing surveys over the years, we can determine the changes that the structure and its surrounding context have undergone. The changes from the original state, identified through the survey between 1990-2001, are marked in blue. Notably, the rosette on the southeast wall was walled up, as well as the door leading to the guest room on the northeast side. Changes following the 2013 survey are marked in red and yellow, where yellow indicates demolition interventions, and red marks new elements. Demolition interventions primarily involve clearing the surfaces of the building from plaster and demolishing a one-story structure built adjacent to the northeast side of the tower. A new element is the roof, which was restored in 2013 by adding a waterproofing membrane and a wooden floor under the flag stone elements, presented in fig 2.

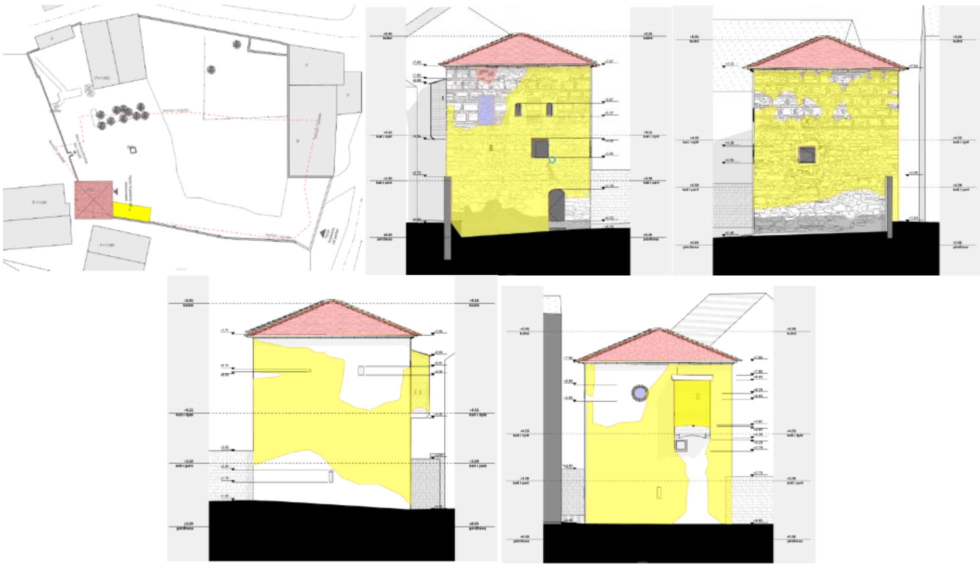


Figure 2. Interventions over the years in building-Kulla Ymer Poga

2.3.1. Conservation and Restoration Interventions

The building represents historical value, as one of the oldest examples of tower-type Kulla- buildings in Kosovo. Additionally, it stands out for its characteristic facade treatment and the semi-spherical dome covered by a four-sided roof.
Based on Point 5 of the Conservation Principles of the Charter on Built Vernacular Heritage (1999), ratified by the 12th General Assembly of ICOMOS, in Mexico, October 1999: "Vernacular includes not only the physical form and shell of buildings, structures, and spaces, but also how they are used and

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

understood, as well as the intangible traditions and relationships attached to them.", the base steps are listed as follows:

- Consolidation interventions (walls, the dome, and floors)
- Supplementary interventions (elements that have partial or total deficiencies)
- Liberating interventions (walls added with inappropriate materials or in positions that compromise the unity and values of the monument)
- Restorative interventions (plastering, windows, internal stairs, ground floor

The approach to the project is closely related to the exceptionally unique historical and architectural values that this monument represents, as one of the oldest towers in Kosovo (if not the oldest that is still intact). Based on this fact, the project aims to preserve the authentic features of the monument as much as possible, making minimal interventions, which consist of consolidating the building and avoiding other adaptive interventions [3].

2.3.2. Proposal Interventions in Restoration process

The interventions are oriented in each damaged positions, carefully taking into account the typical characteristics of the monument. These interventions encompass all key structural and architectural components, including the walls, floors, ceilings, stairs, and roof, ensuring the restoration maintains the tower's original, integrity and cultural authenticity.

2.3.2.1. External stone walls

In scope of the interventions steps for the wall positions are apply:
-Clean the surface of the stone walls
-Replacement the damages horizontal wood beams
-Replacement the lime mortar and eventually reinforced the structures with injection filling method
-Replacement the stone elements in perimeter of windows
-Replacement the stone elements in perimeter of wall foundation in needed positions
Based on the actually state of buildings are presented through the photos in fig.3.

Figure 3. Proposed interventions in stone walls

The stone walls represent the stability of the structure and this is reason for starting the interventions in these positions using the different methods and materials.

2.3.2.2. Restorations and demolition process of ground floor

Recommended parameters for interventions are based on the previous state and remove all the interventions in over the years realized without any concept for Cultural Heritage Buildings.
The monument maintains its planar layout on the 1st and 2nd floors, while on the ground floor the plan is restored to its original state. The first scenario on remove the interior wall , realized in over the years is presented in fig.4.

Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia
Copyright © 2025 CroCEE
DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

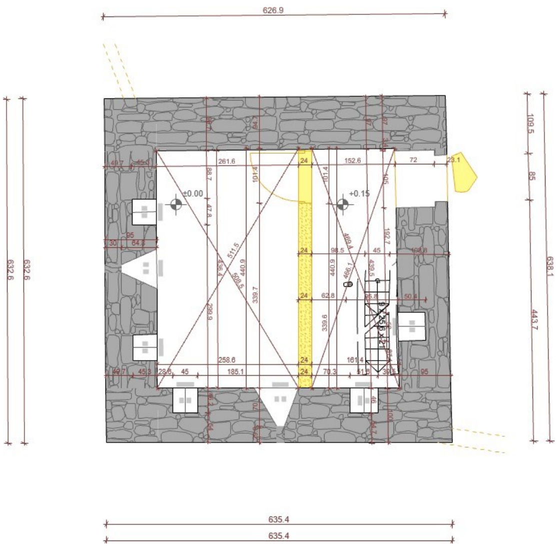


Figure 4. Demolition and remove the interior wall

2.3.2.3. Restorations the floors

Interventions in ground floor are oriented in stone floor with flag stone elements, based on the entrance door model to create the stiff ground floor system using the heavyweight of the stone elements, presented in fig.5.

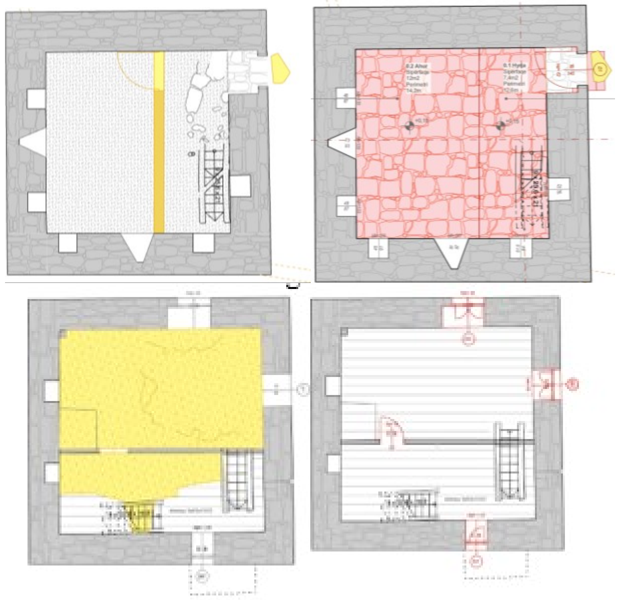
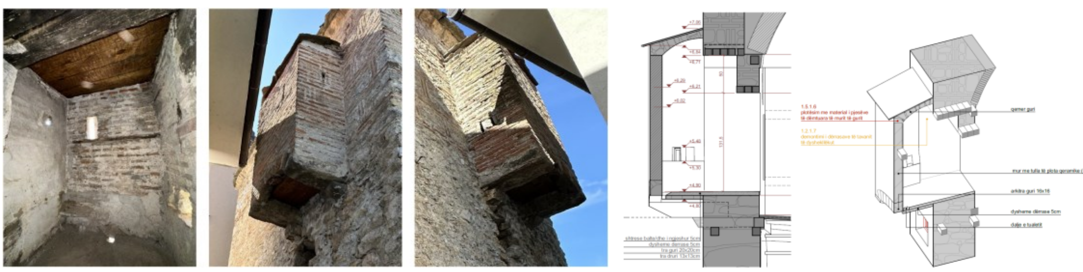


Figure 5. Restorations the ground floor with stone elements and floor restoration (right photos)

The demolishing and restorations of the first and second floor based on the actual system and materials: wood boards in combinations with clay will replace with new wood board, following all the parameters for Cultural Heritage Buildings, in scope of the typically view, presented in figure 5.



Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

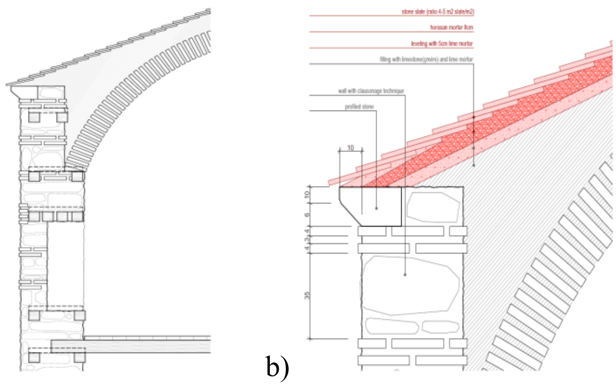
DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

Figure 6. Analyze and proposal for restorations the protruding gallery

One of the main features of the monument's plan is the perimeter outside space(protruding gallery-dyshekllak)   located at the 2nd floor level, which was an element not commonly used in these tower-kulla typologies, presented in figure 6.

2.3.2.4. Restorations the roof-dome

Specifically the roof restorations is one of the important Cultural Heritage element, because it’s dome surface , characteristics in this typology of building , including the elements and materials, presented in Fig 7.a &b

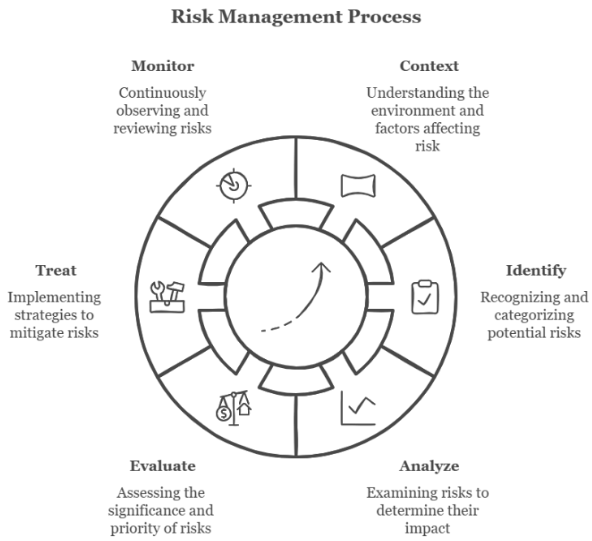


a) b)

Figure 7. Roof – dome existing section(a) and Roof – dome proposed layers(b)

2. Risk management of Cultural Heritage Buildings

To the heritage sites, risk management is the process that involves managing losses of value an impacts in order to minimize them and to reach a balance between opportunities gained and lost. Climate change impacts on cultural heritage are illustrated by several incidents such as flash floods, earthquake in different years results with damages on the existing buildings. However, one of the international standards of the risk tool is ISO 31000:2009[4]. Management Principles and Guidelines. Fig. 8 shows the main six steps in the historical and heritage risk management cycle (context, identify, analyze, evaluate, treat, then monitoring). This risk management principle was considered in this study.[5]. Risks to heritage sites are dependent on the nature, specific characteristics, inherent vulnerability and geographical environment of the site. From another perspective they are dependent on the nature of the external threats affecting the heritage itself.[12]



Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

Figure 8. Risks and agents of deterioration potentially affecting the integrity of heritage sites © UNESCO

2.1.Risk in Practice-Cultural Heritage Buildings

From developmental perspective, the most critical risks to heritage properties would be to people, property and livelihoods. But from conservation perspective, risk assessment of these properties would mean consideration for three important heritage elements, which may be at risk in themselves and for their interrelationships: local communities, ecology and standing as traditional structures. The Cultural Heritage at risk would imply risk to one or all of these elements of structures.[6]. Risk analysis is the scientific and technical study of risks, leading to a full description and model of the processes causing the risks to cultural heritage properties. Based on the information sets collected from various sources, hazards and vulnerability factors can be analyzed as follows: Analyzing the external sources and agents of risk hazards; Analyzing the external sources and agents of risks-hazards; Analyzing vulnerability factors that expose various elements of the property to risk from hazards.[12]. The building risk scenarios can be of various types and the typical concept is presented in figure 9.

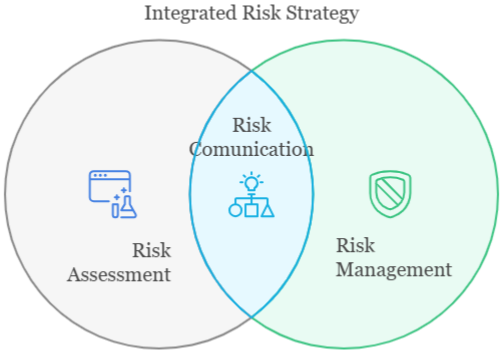


Figure 9.The risk analysis framework with the elements risk assessment, risk management and risk communication [8]

3. Structural analyses of building-Case Study: Kulla Ymer Poga

The analyzing building is typical Albanian tower-Kulla, built more than 3 centuries ago. In scope of the analyzing the element of structures, it characterized with thick walls made from stone , such building material at that time. The floors are from the wood materials, including the wooden beams and wooden elements in combinations with clay. The roof is typical design, constructed in dome shape with clay bricks and lime mortar, support in four points. From visual inspections in scope of the structures it result with high damages from different factors, specifically the environmental factors. The detail analyses of taken samples for testing in laboratory are done in Laboratory IBMS-Prishtine, and based on the outputs of testing, using the software ETABS , is simulated current and possibility retrofitting conditions of the structure. The numerical analyses and create the model provide e realistic view of reactions the building and level of absorptive the capacity under applied loads. In table 1- are presented the properties of testing materials.[9].

Table1. Properties of testing materials

Materials	f_b (MPa)	f_m (MPa)	f_k (MPa)	E (MPa)	G (MPa)	E_m (MPa)	G_m (MPa)
Non damage wood-Humidity 12%	7.10			96 000	38 400		
Damage wood	0			0	0		
No damage stone	203.51			35 000	14 000		
Damages stone for basements	22.52			22 520	9 008		

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

Mortar		7		7 000	2 800		
Clay Bricks	5.47			5 470	2 188		
Stone wall			74.04			33 318	13 327.2
Damage stone wall			15.86			7 137.4	2 854.96
Dome with clay bricks			5.89			2 650.5	1 060.2

The calculation of the characteristic value of the masonry using the characteristic values for brick and mortar is taken from EC6, the characteristic compressive strength of masonry should be determined from equation 1.

$$f_k = K\, f_b^{\alpha}\, f_m^{\beta} \qquad (1)$$

f_k – characteristic compression strength of masonry
K – is constant from tab.3.3 page 37, EC 6-1-1 2006

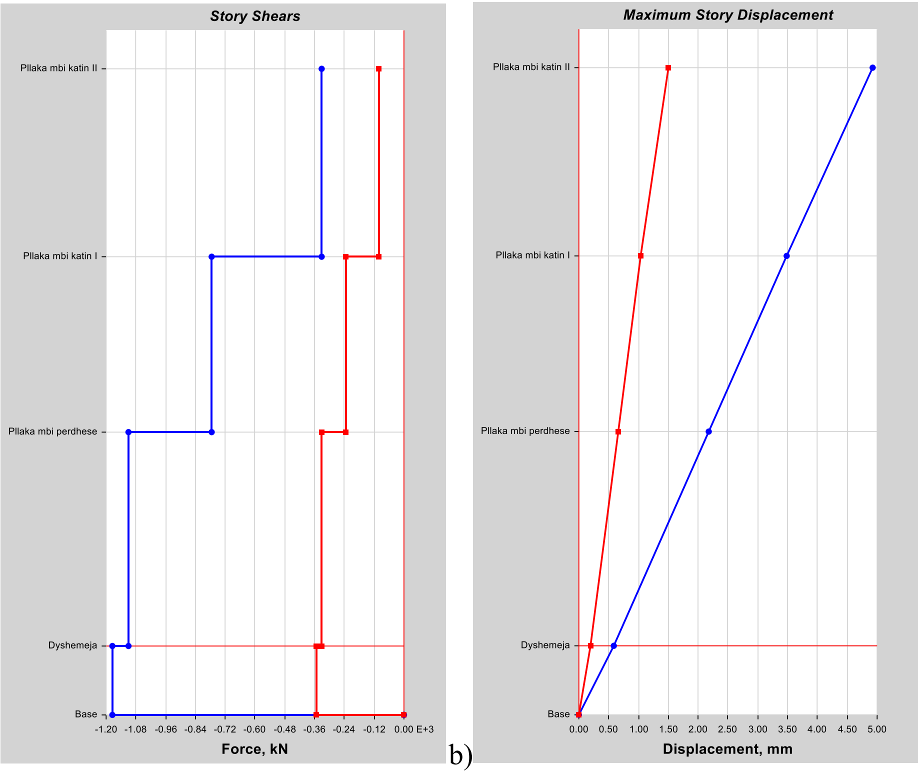
α, β – are constants
f_b – normalised mean compressive strength of units
f_m – is the compressive strength of mortar.

Based on the calculations the continues process is Modulus of Elasticity and Modulus of Shear

$$E_m=1000\ f_k;\ G_m=0.4\ E_m \qquad (2)$$

Under the given earthquake of peak ground acceleration (PGA) of 0.24 ag/g, the response of the masonry structure was analyzed to assess its performance. Since the structure is composed of stones and lacks structural elements that can absorb the energy and it does not possess designated zones for plastic deformation, leading to the adoption of a behavior factor q=1.5. From the analysis, it was determined that the structure can withstand base shear forces up to 1200 kN. The maximum deflections observed were 4 mm, and the presence of cracks was confined to the zones experiencing tension stresses, indicating the points of vulnerability under seismic loading. The following figure represents the building response before retrofitting.

Figure 10.a) illustrates the distribution of shear forces across the stories of the structure under seismic loading. Higher forces are typically observed at the lower stories due to the cumulative effect of inertia from the upper levels, while the forces decrease progressively towards the top of the structure. The second figure, 10.b), represents the displacement profile of the structure, showcasing the lateral movement experienced by each story due to the earthquake. The maximum displacement observed is 4.6mm.



a) b)

Figure 10. Story shears and maximum story displacements, before retrofitting.

Retrofitting measures were implemented, primarily aimed at increasing the stiffness of the walls, which resulted in a noticeable reduction in the structure's fundamental period. This reduction in period correlates with a shift to a lower pseudo-acceleration range, thereby decreasing the seismic forces acting on the walls as per the analysis. Consequently, while cracks remain a factor under tension zones, the retrofitted structure demonstrates a more favorable response under the seismic conditions analyzed, showcasing the benefits of the strengthening measures applied. The retrofitting measures implemented not only enhanced the stiffness of the structure but also provided critical confinement to the masonry units. This confinement significantly improved the durability of the individual stone elements, ensuring they did not shatter or break apart like Lego pieces during the seismic event. The increased cohesion among the masonry units allowed the structure to maintain its integrity beyond the initial impact of the earthquake, providing resistance and stability throughout the seismic motion.

The following figure 11 presents the elastic response of the system after incorporating the effects of retrofitting into the model. This response reflects the improved performance of the structure, showcasing how the retrofitting measures enhanced its ability to withstand seismic forces. By increasing the stiffness of the masonry walls and providing confinement to the structural elements, the retrofitted model demonstrates a more favorable elastic behavior, effectively reducing deformations and mitigating potential damage under seismic loading conditions.

Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia
Copyright © 2025 CroCEE
DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

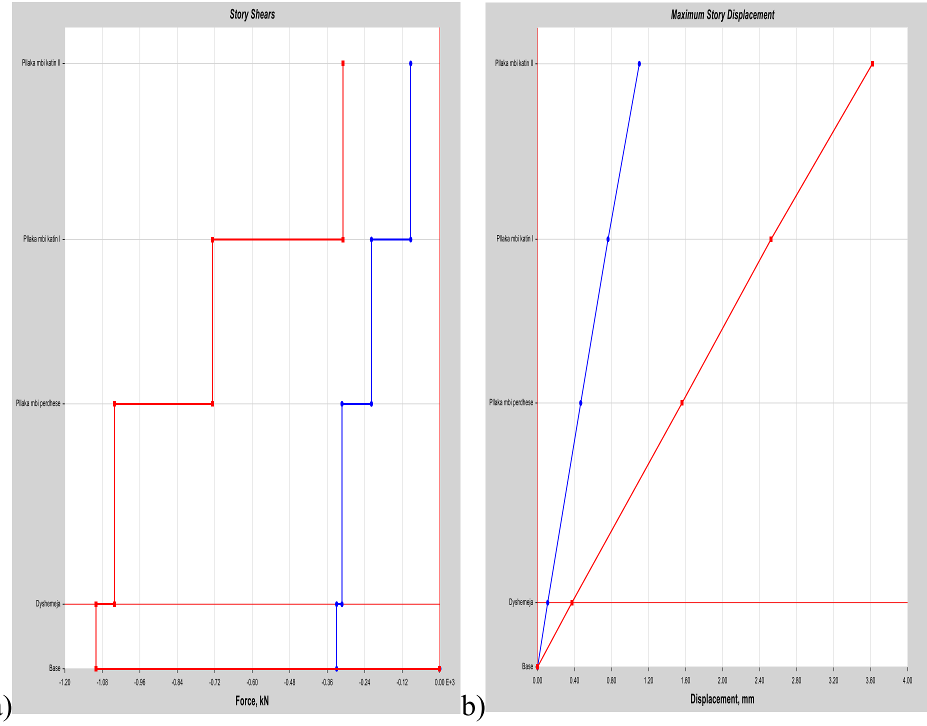


Figure 11. Story shears and maximum story displacements, after retrofitting.

Figure 11.a) illustrates the distribution of shear forces across the stories of the structure under seismic loading. The second figure, 11.b), represents the displacement profile of the structure. The maximum displacement observed is 3.6mm.
Figure 12 illustrates the distribution of stresses, measured in MPa, within the wall under a seismic load combination. This stress map provides critical insights into how the seismic forces are distributed across the structure, identifying areas of high stress concentration that may be prone to cracking or failure.

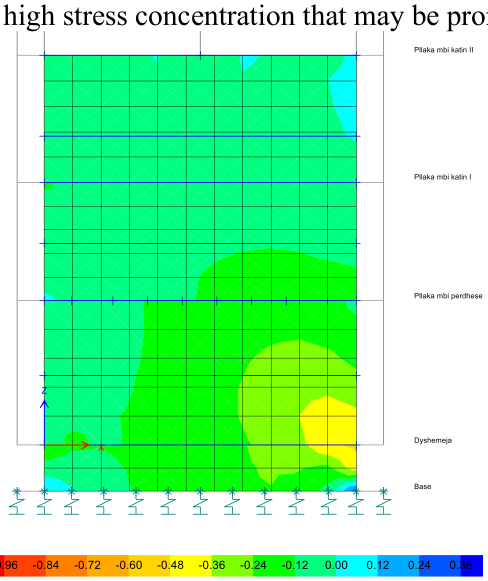


Figure 12. Normal stresses on the wall.

Table 2. Comparing retrofitted structure and non retrofitted structure behavior.

Materials	Shear at base	Displacement	Tension on the wall	Period
Non retrofitted structure	1150kN	4.8 mm	0.06MPa	0.186s
Retrofitted structure	1100 kN	3.6 mm	0.05MPa	0.184s

Proceedings of the 3rd Croatian Conference on Earthquake Engineering - 3CroCEE
19–22 March 2025, Split, Croatia

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

After the statically analyses and proposal for restoration is presented in figure 13.

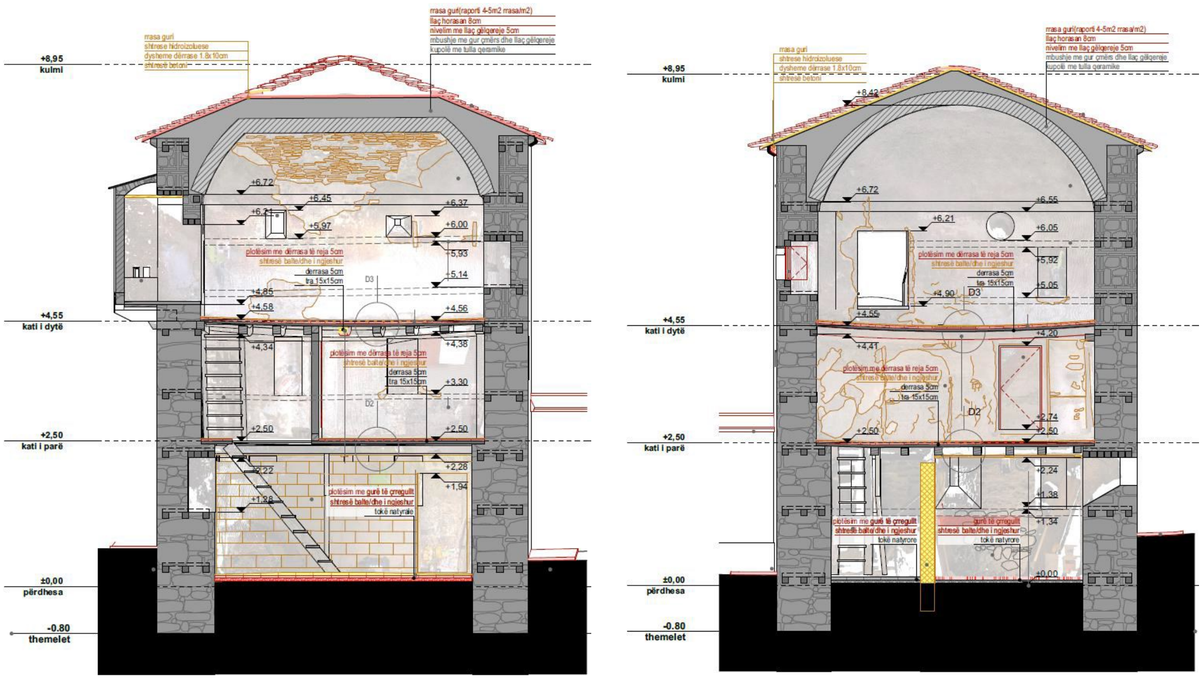


Figure 13. Proposal for Restoration the Kulla Ymer Poga

4. Conclusions and recommendations

The analysis conducted in this project aims to validate a protocol for Cultural Heritage Buildings and risk management, demonstrating its effectiveness as a tool for maintenance, conservation, and restoration efforts. Based on our case study and findings, we present insights that may interest engineers and architects engaged in theoretical research, material analysis, and restoration proposals:

- Involve technical specialists (architects, engineers, chemists, physicists, historians, archaeologists, and economists) from various disciplines in an integrated approach to managing Cultural Heritage Buildings.
- Develop a comprehensive quantitative and qualitative assessment of the environmental, economic, and social impacts of the entire restoration process.
- Define criteria and methods to identify, prioritize, and engage all stakeholders at every stage of the restoration, conservation, and valorization process.
- Design a complete framework of impact indicators to ensure the sustainable restoration of Cultural Heritage.
- Regarding the Kulla-Tower, the analysis of supporting conditions and the mechanical properties of its materials confirms that the numerical model satisfactorily reproduces the structure's dynamic response.

Recommendations Based on the Case Study:

- Design a detailed activity plan for the demolition process and verify stability after each step.
- Adjust the process steps as needed, incorporating preventive measures to address potential changes in structural stability.
- Pay particular attention to wall constructions, as these elements are critical for the structure's load-bearing capacity.
- Recognize that roof systems vary from building to building, and wood deterioration differs, necessitating detailed material testing for accurate assessment.

DOI: https://doi.org/10.5592/CO/3CroCEE.2025.55

Acknowledgements

All authors contributed to study conception and supported from **Ministry of Educations Science and Technology**, through bilateral project: **Repairing the structure using the methods and applications the FRP**

References

[1] Romeu Vicente,Sergio Lagomarsino,TiagoMiguel Ferreira. : Cultural Heritage Monuments and Historical Buildings:Conservation Works and Structural Retrofiting: Chapter, Springer Nature,2017(pp 25-57).

[2] https://gjakovaportal.com/al/trashegimia/kulla-e-ymer-pog235s

[3] Fatemeh Hedieh Arfa,Hielkje Zijlstra,Barbara Lubelli,Wido Quist, Adaptive Reuse of Heritage Buildings: From a Literature Review to a Model of Practice, DOI:10.1080/17567505.2022.2058551,2022

[4] Sesana Elena,Gagnon Alexandre S,Ciantelli Chiara,Casser Joann,Hughes John J. Climate change impacts on cultural heritage: A literature review¸ DOI 10.1002/wcc.710,July 2021

[5] Jose Luiz Pedersoli Jr, A Guide to Risk Management of Cultural Heritage,2016

[6] Rohit Jigyasu , Risk Assessment of Cultural Heritage : Tools & Methodology,2019

[7]. Maarten Nauta, Rikke Andersen, Kirsten Pilegaard, Morten Poulsen, Meeting the challenges in the development of risk-benefit assessment of foods, DOI: 10.1016/j.tifs.2018.04.004,2018

[8]. Tiago M. Ferreira, Xavier Romão, Paulo B. Lourenço, Esmeralda Paupério &Nuno Martins. Risk and Resilience in Practice: Cultural Heritage Buildings, DOI: 10.1080/15583058.2020.1759007,2021

[9] Liubov Lisienkova 1*, Tatyana Shindina 2, Tatiana Lisienkova 3, Development of a Methodology for Assessing the Technical Level of Cultural Heritage Objects in Construction, 2021

[10] Anna Paolini,Azadeh Vafadari,Giorgia Cesaro. Mario Santana Quintero,Koen Van Balen,Ona Vileikis. Risk management at heritage sites:A case study of the petra world heritage site,2012

[11] Florina Jerliu,Kaltrine Thaci,Building typology of Albanian Kulla stone houses in the Balkans,2024

[12] Fatma ELaradi,Saber Kh.Elmabrouk, Risk Assessment at Heritage Sites: A Case Study of Tripoli Old City, Libya,2018