

Structural assessment of historical buildings: a case study of five Ottoman Mosques in Albania

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ABSTRACT

A large portion of Albanian cultural heritage buildings is made of masonry. Many of them due to the decay and degradation of building material, aggressive environmental conditions, frequent seismic activity and various geological phenomena, as well as the lack of maintenance, are found to be in a very bad condition. This paper aims to introduce a case study in structural assessment based on visual inspection of five Ottoman mosques; Naziresha's Mosque in Elbasan, Mirahor Ilyas Beg Mosque in Korça, the Leaden Mosque in Berat, Murat Beg Mosque in Kruja and the Mosque of Preza, built in Albania during the Ottoman period that are still functional nowadays.

Suggestions for improvement of structural capacity and strengthening techniques are proposed taking into consideration preservation of the cultural, historical and architectural values of the mosques.

INTRODUCTION

Masonry is one of the oldest materials used in construction of civil structures and it is closely related with the history of mankind. Early civilizations have left their marks on the planet by building monuments which have been standing ever since, being admired and visited even today. They were built in the past based on the master's knowledge and experience when neither scientific research, nor design standards were available. By trial and error, people managed to build from scratch engineering and architectural masterpieces.

As these structures were built when no detailed rules or regulations were applied, many buildings' current structural conditions do not satisfy the present guidelines. Natural disasters, aggressive environment and human intervention have caused extensive damage to these structures, many of which have been built with no considerations of these factors.

Albania is one of the oldest countries in Balkan Peninsula and Europe. There are many historical structures made of unreinforced masonry units (URM) that carry significant importance due to their unique, cultural, historical and architectural values. Such a fact highlights the need for preserving this cultural heritage group as one of the most immediate issues to be resolved. Many historic monuments in Albania suffer from structural deficiencies, and lack of maintenance. If left in these conditions, their service life will be short. Unfortunately, there have been no large scale attempts to repair and restore them.

What makes a building and a structure historic is: its association with acts of historical importance and its oldness, which means the time that has passed since its construction is considerable.

However, old is a relative term. In practice, it can be used to define a structure 50-100 years old. For ancient constructions, a building is considered to be historic if a few centuries have passed since the time it was built [1].

Due to their historical and architectural values, people nowadays require them to have a longer service life. These types of buildings need to be preserved for the next generations. Thus, there is a need for strengthening and retrofitting.

It is crucial to recognize that before any intervention for repair or strengthening, a correct and comprehensive evaluation of the observed structural defects should be performed. Those problems could be solved and eliminated for the future if were based on a correct diagnosis.

LITERATURE REVIEW

Historical buildings include representative values for a certain epoch, place, community, knowledge, materials and workmanship, techniques and technologies, local traditions, local community, previous and neighboring cultures, social and political background and so on [2].

Many URM buildings are found in regions with high seismic activity. Recent earthquakes have pointed out the vulnerability of these structures against seismic shaking. In order to preserve and extend their service life, strengthening strategies should be developed. A lot of research papers and similar thesis have been studied and outcome is extracted and arranged in a logical sequence adapted for this study.

In 1989, Matthys and Noland estimated that more than 70% of the world's building inventory was made of URM. A large number of the total population, due to lack of economical resources, lives in non-engineered, sub-standard dwellings which are extremely vulnerable to collapsing. These figures have probably changed during the following years, but still remain high. Moderate or strong earthquakes may cause extensive damage or failure of these structures, killing many people and injuring thousands. Since demolishing is not a feasible option, strengthening and improving earthquake performance under cyclic ground shaking can be a good solution [3].

Strengthening, retrofitting, and repair of historical structures attempt to mitigate the associated hazards coming from natural disasters and deterioration of structure during time, and improve load resisting capacity as well as extend the service life of these structures.

The fact that they have survived until today, shows that their structural form and material properties combined together have resisted ground shaking affects and deterioration in time. However, some of the reasons for the structures to be strengthened are [4]:

- i. To eliminate structural problems or distresses which result from unusual loading and exposure conditions, inadequate design or poor construction practices. These distresses may be caused by overload, fire, flood, foundation settlement, deterioration, possible earthquakes, etc.
- ii. To correct design or construction errors,
- iii. To resist exceptional or accidental loadings,
- iv. To increase tensile, shear, flexural or compressive strength of structural members.

All interventions should be carefully planned and performed. Structural interventions have to assure structural compatibility with the original structure, keeping its original form as much as possible. Modified or new structural elements should not disturb the architectural appearance and aesthetics of the building [2].

Many books have been written about the history of Albania from national and international historians. A lot is written about the Albanian historic monuments too. However, less research is done for repair and restoration of those structures.

M. Kiel, in 1990, in his book “Ottoman Architecture in Albania 1385 – 1913” has provided an inventory of structures built at that time. A lot of information for the considered mosques has been studied based on this book [4].

Many tuff masonry historic structures have been constructed in the past centuries. These types of buildings are typical constructions of Southern Europe of that period. They are generally fit for bearing vertical loads, but are weak to resist cyclic horizontal actions induced by seismic shaking. Recent earthquakes have pointed out the lack of seismic resistance of these structures [5].

Assessment of seismic vulnerability of historic masonry constructions is a very challenging task due to several uncertainties regarding mechanical properties and geometrical characteristics of the structure. Each masonry building is unique. Hence, it should be treated with special care. A correct structural analysis of the building requires a deep knowledge of building history and evolution, geometry, structural details, material properties, cracking pattern and masonry construction techniques. An accurate structural system can be developed by combining in-situ and laboratory test results. Generally, obtaining all the needed information for properly defining the numerical model is very difficult or even impossible. Because of this reason, simplified and iterative procedures of assessment are required.

Vicarious Palace in Pescara is an example of seismic vulnerability assessment where a finite element modeling analysis was applied. Comparison of the expected seismic demand versus the seismic capacity of the palace confirmed the weakness of this building typology against earthquake forces. The obtained results are an indicator for other buildings of this [6].

Gülkan et al, 2009, introduced a practical method for condition assessment of historic structures. According to this method, it is important not to change the load-carrying mechanism of the structure as it may cause further unknown problems in the future.

Casarin and Modena conducted a seismic assessment of Santa Maria Assunta a Cathedral in Reggio Emilia, Italy. Evaluation of structural conditions was performed using different investigation and analysis methodologies (limit analysis and numerical approach) [7].

The suggested strengthening technique for Mihrimah Sultan Mosque, after a 3-D FEM analysis used to simulate static and seismic behavior of the mosque, of application of tie rods at both ends of the supported arches estimated a reduction of the compressive stress at the supports by 29-54% [8].

Lourenço et al, 2001, in their study, conducted assessment of seismic behavior of a basilica church, defining the most vulnerable parts and identifying the possible failure mechanisms. This analysis was carried out by 3-D modeling with geometric simplifications which provided the main characteristics and behavior of the structure. In some cases, since there are many uncertainties, the undertaken assumptions and simplifications can often mislead from the actual behavior [9].

BACKGROUND AND CURRENT CONDITIONS OF OTTOMAN MOSQUES IN ALBANIA

Republic of Albania is found in the Southeastern Europe, in Balkan Peninsula bordering with Adriatic and Ionian Sea to the west, between Greece in the south, Montenegro and Kosovo in the north and FYR of Macedonia to the east (Figure 1). Albanians are one of the oldest populations of Europe, descendants of Illyrians (Indo-European people) who settled in today's lands in 1000 B.C. Albania's history is rich of historical events. However, this study is focused on the historical monuments built during Ottoman Empire (1481-1912).

The classical period (1437-1703) is the time when for the religious constructions it was adopted a single dome for covering large inner space. One of the major features of this period is monumentality.

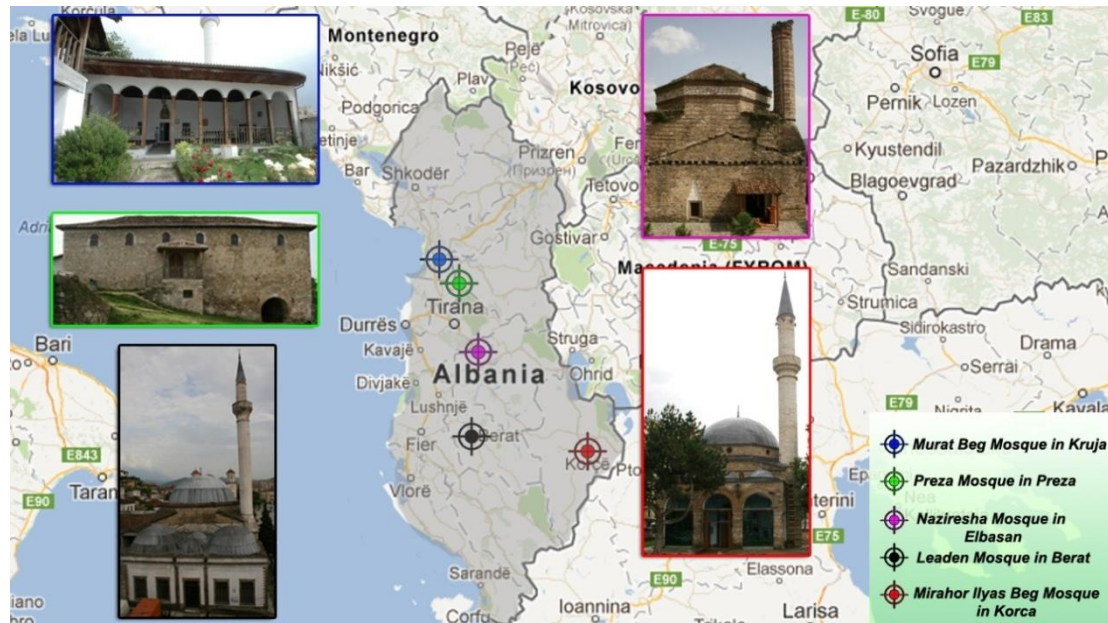


Figure 1. Map of Albania and the locations of the studied mosques

The Leaden Mosque in Berat

Leaden Mosque is one of the massive well-preserved mosques found the city center of Berat. The mosque which was built by the Skuraj family in 1553-1954, used to be part of a large assemble. The comprising parts of the mosque are: a prayer hall having 12 m x 12 m squared plan, the last prayer hall and the minaret. The cubic mass and the dome are connected by melon-like ribbed pendentives. The triangular shoulders covered with clay tiles, are arranged in such a way to provide a base for the octagonal drum. The last prayer hall is covered by four domes, two of which are supported by two marble columns at the center of the porch.

The south-east façade of the mosque is built by horizontal yellow limestone bricks bonded together with red clay bricks placed vertically [10].

The Mosque of Preza

The mosque of Preza is located in Preza district in an archaeological area inside the Preza castle. The mosque was built in 1547 on the castle walls.

The mosque of Preza has a rectangular prayer hall with dimension of 7.30 m x 19.00 m. The walls made of rubble stones are all load bearing and have a thickness that varies from 0.40 – 1.35 m. The structure is covered by a wooden pitched roof with marseille tiles. Original ceiling is not present. The current one is covered with a layer of plywood. The minaret has been destroyed. Today's remains of it can be seen up to the plinth level [4].

Murat Beg Mosque in Kruja

Murat Beg Mosque is situated a few hundred meters away from the main entrance door of the Kruja Castle. It is popularly referred to as the big mosque. It was built during 1533-34. It has a simple timber construction which was one of the easiest and practical methods of construction of that time and was rapidly spread in the cities nearby too.

Mirahor Ilyas Beg Mosque in Korça

Mirahor Ilyas Beg Mosque, built in 1496 in Korça, is one of a few Ottoman mosques still existing in Albania and the only Ottoman monument in the city, located near the city center. It has a significant importance for the city of Korça as it is strongly associated with the development of the city as an urban center. It was named after its founder Mirahor Ilyas Beg.

The mosque of Mirahor Ilyas Beg has a strong image; a cubic mass rising over a square plan consisting of two parts: the prayer hall having a square schemed plan of 11.75 m long and the last prayer hall having a rectangular schemed plan with three piers.

Transition from the cubic mass to the dome in this building is done by pendentives which are divided into ten melon-like ribs. Triangular shoulders are covered by leaden plates and they prepare the octagonal drum for the dome. The main dome raises 14.6 meters above the ground. It has a semicircular shape and is covered with a leaden layer. The main dome and three semi domes which cover the last prayer hall constitute the main roofing system of the mosque.

Neatly cut stone and bricks are used for building of the mosque. Every stone is surrounded by two layers of horizontal and vertical bricks. The pendentives and the dome are constructed with bricks. The distance between the columns is spanned by pointed Ottoman arches made of bricks.

Interior of the mosque is painted in white. There are paintings of famous mosques. There is a big lantern hanged at the dome. Pendentives are adorned with stalactite decorations [11].

Naziresha's Mosque in Elbasan

Naziresha's Mosque is one of the most important historical buildings built during the Ottoman period, still functional in Albania. It is located in Elbasan, a city in the Central Albania. Built in 1590s in the southern suburb of the city, it is the only preserved Ottoman mosque of the city.

The Mosque of Naziresha was built in Ottoman style. It has a squared 10.70 x 10.70 meters plan and only one cubic shaped central hall. The walls made of stone comprise the main load bearing system of the mosque. They are 1 meter thick and rise until a height of 8.12 meters. The materials used for building of the walls are rough yellowish limestone and red bricks.

Transition from the cube to the dome is provided by pendentives. They are covered from outside by triangular shoulders. The dome rises over the pendentives 14 meters above the ground. It is made of bricks and has a thickness of 0.35 meters.

Roofing system is made of baked clay tiles attached to timber frame. Interior of the mosque was newly plastered and painted in white and green. It has a special acoustic system providing the sound to be heard clearly at every corner of the mosque. The minaret is placed at the west corner. It is made of neatly cut blocks combined with three layers of thin red bricks. It is damaged and the upper section is missing [16].

INSPECTION AND ASSESSMENT PROCEDURE

In order to perform the inspection efficiently, a simple inspection and assessment form has been adopted from Gülkan [1]. It consists of: general details of the structure (address, rough area, number of story, height), type of roof, material types, condition of load bearing elements, condition of the connections, earthquake hazard level, possible failure mechanisms, etc. At the end, recommendation is given whether to retrofit, demolish or conduct further analysis. Rating of severity levels is from none (contains no structural damage), light, moderate, severe to near collapse (a heavy damaged element or structure).

The outcome obtained from the visual inspection provides a general assessment of the current structural conditions based on the visual “symptoms”. Based on the final results, the next step to be taken is suggested. It is essential to choose the most compatible solution regarding the current structural conditions of the building, concerning about preserving as good as possible. This assessment procedure provides a general overview of the current structural conditions of the mosques. It provides the first step in preparing the analytical and computer model.

ASSESSMENT RESULTS

Assessment results have shown that all of the five mosques suffer from damages and structural problems. The most endangered mosque is Naziresha’s in Elbasan, whose current structural conditions could be stated as “severe”. Massive cracks and structural problems are observed. The assessment results are summarized below:

Roofing system composed of domes or timber pitched roofs, exhibits a lot of deficiencies. Due to the improper isolation, in Naziresha’s, Mirahor Ilyas Beg and Leaden mosques spall of plaster is seen. In Murat Beg and Preza mosques deformed ceiling, rotten timber elements and broken tiles are observed. In Elbasan, over the rooftop vegetation growth is seen.

Structural conditions of the roof system of Mirahor Ilyas Beg Mosque in Korça seem adequate to carry static loads. However, there are found many structural cracks. Improper connection of the lanterns hanged at the top of the ceiling, in a later time after the dome was built, has caused extra local stress concentrations causing cracks around the connections (Figure 2).

Other structural cracks may have been caused by earthquake loads. Improper isolation of the roof system, high level of air humidity, leakage and penetration of rainwater inside the structure has caused dark moisture spots in the interior of the mosque.

Spall of plaster can be seen in some zones. There are also found cracks related to the old age of the building and amortization during time. Pendentives and arches suffer from the same problems. Thrust transferred from the dome loads may have exceeded their load carrying capacity.



Figure 2. Cracks in the interior of the dome and pendentives in Mirahor Ilyas Beg Mosque

According to assessment results, load bearing walls are the one that suffer most from damage and structural cracks. The most possible causes of these structural problems are excessive stress concentrations such as: compressive stress caused by vertical loads (static), shear stress caused by lateral loads (earthquakes) and propagation of cracks due to successive earthquakes and amortization during centuries [17].

In the load bearing walls of the Naziresha's Mosque serious cracks are present in all façades. Most of the cracks inferred from the damage survey presented a diagonal and vertical trend. Creep of the masonry units is believed to be the cause of vertical parallel cracks which eventually may lead to collapse of the wall. This phenomenon is accompanied by occurrence of chipping and possible local failure. This is very obvious in the north façade where there are massive cracks whose cause is believed to be improper modification of the entrance. Vegetation growth can be seen where masonry units are missing. At the bottom of the walls, due to consequent flooding, sanding phenomenon is seen. There are found voids that grow bigger in time. Crack propagation from pendentives to the load bearing walls is observed in all four façades. In the places where openings are present, a different crack pattern can be seen. Tensile and shear stresses are concentrated close to the edges of these openings possibly due to local concentration of loadings. As a result, every window is cracked at the bottom corners of its frames (Figure 3).

Furthermore, cracks due to differential settlement and suffusion (migration of soil particles through soil skeleton) phenomenon are observed. Hair cracks (small cracks) are seen in the interior of the walls. Further cracks cannot be seen due to local works of rebuilding in the interior of the mosque. However traces of the mentioned cracks of the exterior can be spotted if carefully checked. Based on the problems mentioned above, there is a very concerning situation about structural stability of this mosque.



Figure 3. Propagation of cracks in the load bearing walls, west façade of Naziresha's Mosque

The assessment results are summarized in Table 1 [18]:

	LEADEN MOSQUE	NAZIRESHA'S MOSQUE	MIRAHOR ILYAS BEG MOSQUE	MURAT BEG MOSQUE	PREZA MOSQUE
DATE	09/09/2011	09/09/2011	09/09/2011	09/09/2011	08/10/2011
ADDRESS & LOCATION / ROUGH AGE OF BUILDING [YEARS]	CITY CENTER OF BERAT, GAQI GJIKA STREET / 40.704497, 19.955453 / YES / 360 yrs	KADRI HYSHMERI STREET, ELBASAN / 41.105294, 20.086495 / YES / 421 yrs	FLORESHA MYTEVELI, KORÇË /40.615940, 20.775407/ YES / 525 yrs	PAZARI VJETER STREET / 41.509887, 19.794300 / 477 yrs	PREZA CASTLE/41.4 31257, 19.672667/ YES/ 464 yrs
STRUCTURAL SYMMETRY	EXISTS IN PLAN	EXISTS IN PLAN	EXISTS IN PLAN	EXISTS IN PLAN	EXISTS IN PLAN
ROUGH AREA COVERED	576 m ²	115 m ²	186 m ²	100 m ²	75 m ²
NO.OF STORIES	1 STORY + mezzanine	1 STORY + mezzanine	1 STORY + mezzanine	1 STORY + mezzanine	1 STORY
TOTAL HEIGHT OF BUILDING [M]	11 m	14.2 m	14.59 m	4.20 m	3.30 m
WALL CONSTRUCTION	BRICK & STONE	BRICK & STONE	BRICK & STONE	BRICK & STONE	BRICK & STONE
WALLS ARE LOAD BEARING	YES	YES	YES	YES	YES
STRUCTURAL QUALITY OF WALLS	ADEQUATE	POOR	ADEQUATE	POOR	POOR
TYPICAL WALL THICKNESS[M]	1.05 m	1 m	1.25 m	0.70 m	0.70 m
LATERAL LOAD RESISTING ELEMENTS	DOME, WALL, PENDENTIVE	DOME, WALL, PENDENTIVE	DOME, WALL, PENDENTIVE	WALL	WALL
CONNECTIONS	ADEQUATE	POOR	GOOD	ADEQUATE	POOR
ROOF	DOME	DOME	DOME	PITCHED ROOF	PITCHED ROOF
MINARETS OR OTHER STRUCTURAL APPENDAGES	YES , external Minaret	YES , external Minaret	YES , external Minaret	YES , external Minaret	NO , minaret destroyed
MORTAR / CEMENTING MATERIAL	OTHER : KHORASAN MORTAR	OTHER : KHORASAN MORTAR	OTHER : KHORASAN MORTAR	OTHER : KHORASAN MORTAR	OTHER : KHORASAN MORTAR
DAMAGE LEVEL : WALLS	MODERATE	SEVERE	MODERATE	MODERATE	SEVERE
DAMAGE LEVEL : ROOF	MODERATE	SEVERE	LIGHT	MODERATE	MODERATE

DAMAGE LEVEL : OTHER ELEMENTS 1. Pendentives 2. Wall corners 3. Doors, windows	1.MODERATE 2.LIGHT 3. LIGHT	MODERATE	1.MODERATE 2.LIGHT 3. LIGHT	MODERATE	MODERATE
POSSIBLE FAILURE MECHANISM	B1 OVERTURNING WITH 1 SIDE WING D PARTIAL OVERTURNING	MASONRY FAILURE C CORNER FAILURE Insufficient cohesion in the fabric	E VERTICAL STRIP OVERTURNING H IN PLANE FAILURE	H IN PLANE FAILURE ROOFS FLOORS COLLAPSE	H IN PLANE FAILURE C CORNER FAILURE
EARTHQUAKE HAZARD LEVEL	VERY LOW	HIGH	VERY HIGH (highest Albania) HIGH in	MODERATE	LOW
RECOMMENDATION	RETROFIT.	FURTHER ANALYSIS & RETROFIT.	RETROFIT.	RETR OFIT.	RET ROFIT.

Table 1. Structural assessment results

Moreover, structural deficiencies of each mosque are presented in the figures below (Figure 4-8)

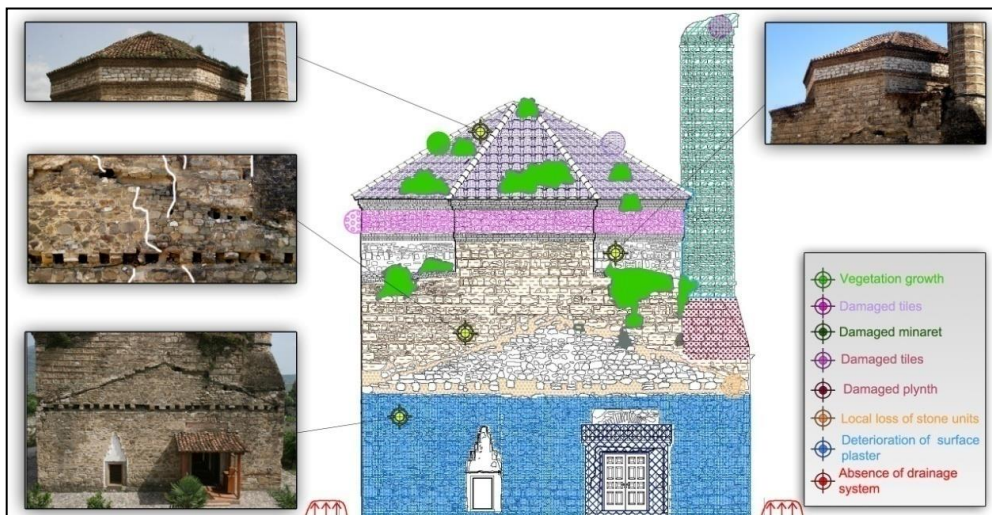


Figure 4. Inspection of structural problems of Naziresha's Mosque



Figure 5. Inspection of structural problems of Murat Beg Mosque

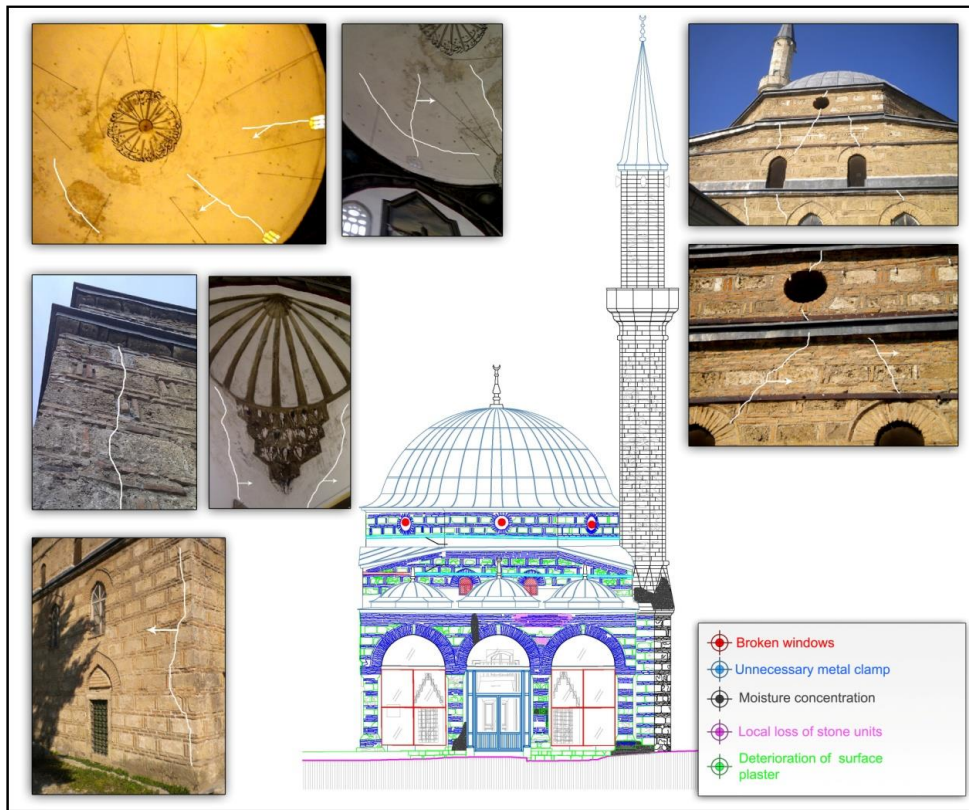


Figure 6. Inspection of structural problems of Mirahor Ilyas Beg Mosque

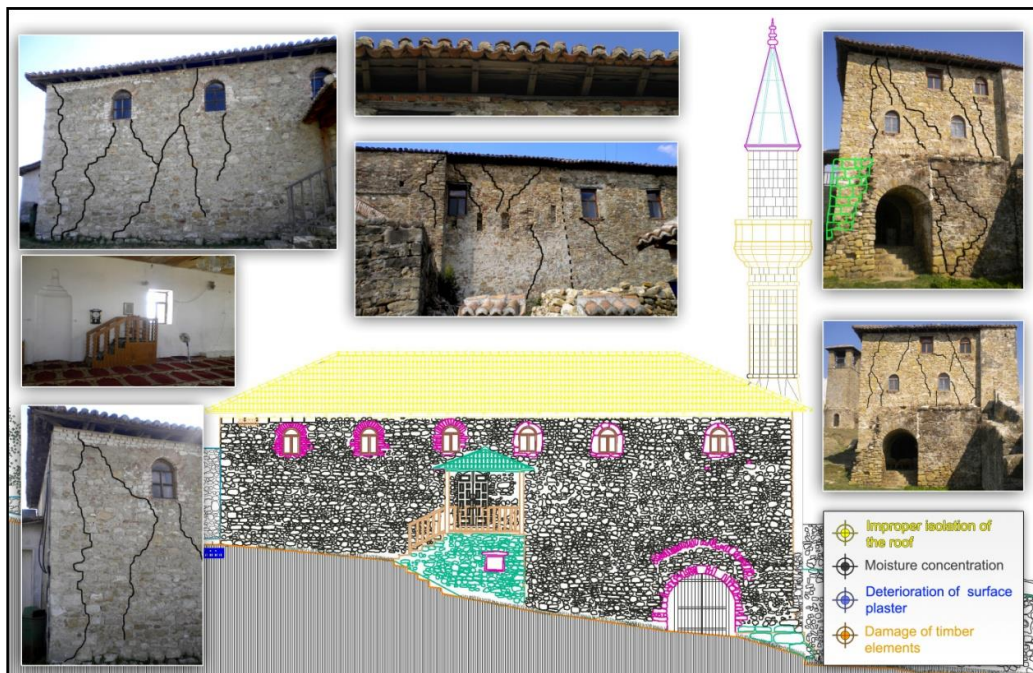


Figure 7. Inspection of structural problems of Mosque of Preza.

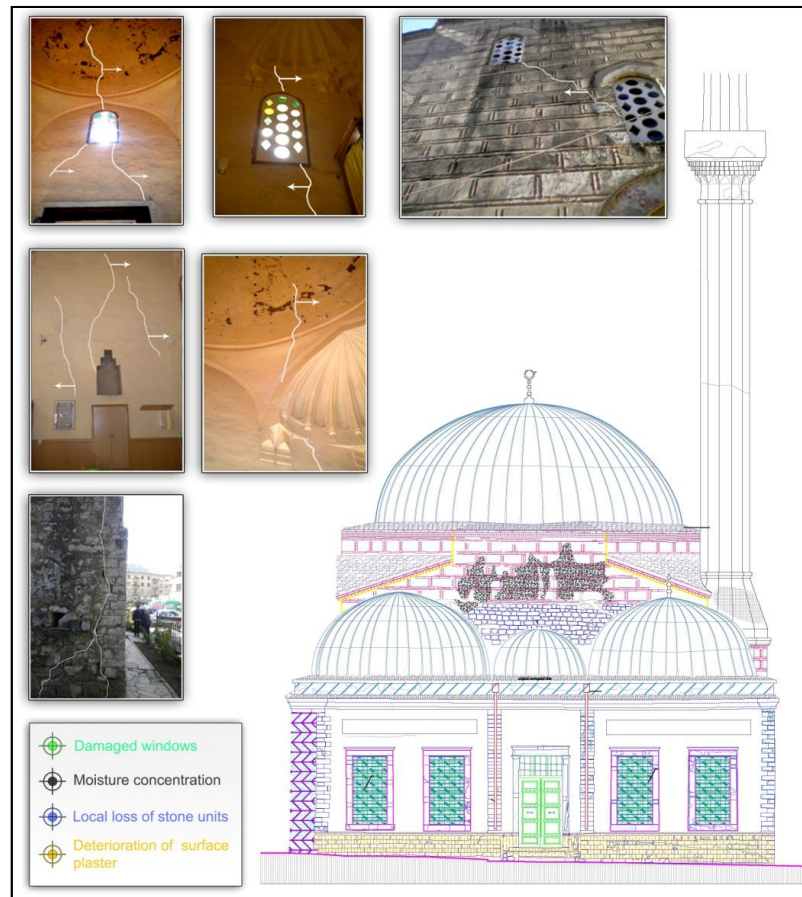


Figure 8. Inspection of structural problems of Leaden Mosque

CONCLUSIONS

In this study, condition assessment of Ottoman mosques and strengthening strategies were discussed. The proposed methodology of visual “symptoms” of structural defects provides useful information about the general overview of the current structural conditions of the structure.

Prevention is better than cure, thus people should be aware to take precautions before the damages of the structure become un-repairable.

If a structure’s assessment results, with the procedure mentioned above, happen to be not satisfactory to sustain loads and stresses that it is constantly subjected, immediate retrofitting and strengthening measures should be taken. Urgent intervention must be carried out in order to avoid the expansion of distresses, and cracks. Great attention should be paid during the restoration process. Apart from the concerns about functionality and structural reliability, it is very important to preserve authenticity of the historic structure. The suggested methods aim to improve the existing capacity of the structure not only for static but also possible earthquake loads.

Furthermore, Korça and Elbasan are located in a highly active zone of earthquakes. Therefore, strengthening of the structure is needed to be done with the consideration of possible seismic activity in the area. Strengthening techniques have to be in accordance with ICOMOS rules and practices.

From the condition assessment results of the five Ottoman mosques, it has been observed that various structural deficiencies are present in all of them. Some of the most common problems are deterioration of surface plaster, loss of masonry units, structural and

non-structural cracks, damaged roofing system, damaged drainage system, sanding etc. The worst structural conditions are seen in Naziresha's Mosque in Elbasan.

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