Research Article

Recurring Seismic Damage in Repeatedly Restored Historic Masonry: A Damage Classification-Based Evaluation of Malatya Teze Mosque*

Lale Karataş Billor[1],
Bursa Technical University, Faculty of Architecture and Design, Department of Architecture, Bursa, Türkiye[1]
lale.karatas@btu.edu.tr
https://orcid.org/0000-0001-8582-4612
Received: 14.04.2026, Accepted: 12.06.2026
DOI: **10.17932/IAU.ARCH.2015.017/arch_v012i1005**

Abstract: This study aims to evaluate earthquake-induced damage in historic masonry structures that have undergone repeated restoration interventions through a damage classification–based approach, using the Teze Mosque in Malatya as a case study. The structure, which has been repaired multiple times over different periods, was damaged and restored again following the earthquakes of 1893, 1964, 2020, and 2023. The research was conducted in two stages. In the first stage, a damage classification approach was developed based on commonly observed in-plane and out-of-plane behaviors, connection deficiencies, and material deterioration in unreinforced masonry structures. This approach is grounded in internationally recognized references such as FEMA 306 and EMS-98 and is further supported by the element-level analytical method proposed by Vlachakis et al. (2020). In the second stage, archival data were used to examine the damage patterns the structure experienced during past earthquakes, and the recurrence and evolution of these damages over time were analyzed. The findings indicate that restoration interventions carried out after previous earthquakes did not improve the structural performance of the building in subsequent seismic events; on the contrary, in some cases, the intervened areas became more vulnerable to damage. One of the most significant findings of the study is the identification of the phenomenon in which restored sections become the first parts to fail. The analyses revealed that certain areas subjected to previous restoration interventions experienced earlier and more severe damage during subsequent earthquakes compared to the original parts of the structure. The main causes of damage include differences in rigidity arising from double-walled construction systems, inadequate structural connections, the use of weak bonding materials, and soil conditions.

Keywords: Earthquake damage, unreinforced masonry, damage classification, structural performance, restoration interventions.

Tekrarlanan Restorasyon Müdahaleleri Sonrasında Tarihi Yığma Yapılarda Yinelenen Deprem Hasarları: Malatya Teze Camii'nin Hasar Sınıflandırmasına Dayalı Bir Değerlendirmesi

Özet: Bu çalışma, tekrarlayan restorasyon müdahalelerine maruz kalmış tarihî yığma yapıların deprem kaynaklı hasarlarını, hasar sınıflandırmasına dayalı bir yaklaşımla değerlendirmeyi amaçlamakta olup, Malatya'daki Teze Camii örnek olay olarak ele alınmıştır. Farklı dönemlerde birden fazla kez onarım görmüş olan yapı, 1893, 1964, 2020 ve 2023 depremlerinin ardından hasar almış ve yeniden restore edilmiştir. Araştırma iki aşamada yürütülmüştür. İlk aşamada, donatısız yığma yapılarda yaygın olarak gözlenen düzlem içi ve düzlem dışı davranışlar, bağlantı yetersizlikleri ve malzeme bozulmaları temel alınarak bir hasar sınıflandırma yaklaşımı geliştirilmiştir. Bu yaklaşım, FEMA 306 ve EMS-98 gibi uluslararası kabul görmüş referanslara dayanmakta olup, ayrıca Vlachakis ve arkadaşları (2020) tarafından önerilen eleman düzeyindeki analitik yöntemle desteklenmiştir. İkinci aşamada ise, yapının geçmiş depremlerde maruz kaldığı hasar örüntüleri arşiv verileri kullanılarak incelenmiş, bu hasarların zaman

* *An earlier version of this study was presented as an abstract at the IV. International Architectural Sciences & Applications Symposium (IArCSAS 2024), held in Girne, Cyprus [39].*

içerisindeki tekrarlanma ve gelişim süreçleri analiz edilmiştir. Bulgular, önceki depremler sonrasında gerçekleştirilen restorasyon müdahalelerinin yapının sonraki sismik olaylardaki yapısal performansını iyileştirmediğini; aksine bazı durumlarda müdahale edilen bölgelerin hasara karşı daha kırılgan hâle geldiğini göstermektedir. Çalışmanın en önemli bulgularından biri, "restore edilen bölümlerin ilk hasar gören bölümler hâline gelmesi" olgusunun ortaya konulmasıdır. Analizler, önceki restorasyon müdahalelerine maruz kalan belirli bölgelerin, yapının özgün kısımlarına kıyasla sonraki depremlerde daha erken ve daha şiddetli hasar gördüğünü ortaya koymuştur. Hasarın başlıca nedenleri arasında çift cidarlı duvar sistemlerinden kaynaklanan rijitlik farklılıkları, yetersiz yapısal bağlantılar, zayıf bağlayıcı malzeme kullanımı ve zemin koşulları yer almaktadır.

Anahtar kelimeler: Deprem hasarı, donatısız yığma yapılar, hasar sınıflandırması, yapısal performans, restorasyon müdahaleleri.

1.INTRODUCTION

When looking at the earthquake hazard map of Europe, countries with a coastline along the Mediterranean Sea, especially Turkey, Greece, Albania, and Croatia, are situated in a major seismic zone. In the past three years, these countries in the region have experienced loss of life and property due to the impact of earthquakes. Turkey is located on several major fault lines, including the North Anatolian Fault (NAF), the East Anatolian Fault (EAF), the Northeast Anatolian Fault (NEAF), and the West Anatolian Fault (WAF). The EAF is one of the world's most active earthquake faults with the shortest return periods. Over the last decade, this fault has been responsible for several major and destructive earthquakes that caused significant loss of life and extensive structural damage. The latest devastating earthquake on this fault occurred in Turkey on February 6, 2023, at 04:17 local time, with a magnitude of 7.7 Mw, and its epicenter was in Pazarcık (Kahramanmaraş) on the East Anatolian Fault. Shortly after this earthquake, approximately 9 hours later at 13:24 local time, another major earthquake with a magnitude of 7.6 Mw hit the Elbistan-Ekinözü region, also in Kahramanmaraş province. These earthquakes caused extensive destruction and significant damages in nearby provinces as well. Malatya, being one of the cities near the earthquake epicenters, was one of the places where significant destruction was observed.

Both modern and historical buildings in the city center suffered considerable damage. One of the most severely affected historic buildings was the structure known as the Teze Camii.The historic Teze Camii, with its social presence in the city center, is considered one of the symbols of Malatya throughout history. Despite undergoing various damages in numerous earthquakes, the structure has been subjected to restoration after each earthquake. However, it is observed that the damages escalate with each subsequent earthquake. Upon reviewing archival records, no studies documenting the types of damages the building suffered after earthquakes were found. Yet, the damages caused by earthquakes in various years present a significant opportunity, especially for understanding the static and material behavior of historical structures, as historical buildings have different characteristics compared to modern constructions, and predicting their seismic response is not a straightforward task. Accurate documentation of damages in historical buildings after earthquakes can provide valuable information for future risk assessments. The types, intensities, and distributions of damages can be analyzed. This helps to identify which parts of the structures are more vulnerable and require strengthening. Consequently, this information guides restoration efforts.

By understanding the types and extent of damages, suitable strengthening methods can be implemented, making the structures more resilient and less susceptible to damage in future earthquakes. In summary, documenting the damages in the historic Teze Camii is a crucial step in mitigating potential damages in future earthquakes. These records can be utilized in various fields, such as risk assessment, strengthening projects, inspection, control, education, and raising awareness, all of which contribute to minimizing post-earthquake damages. The absence of any damage documentation for the historical building in archival records indicates that lessons were not learned from previous earthquakes, despite the damages increasing with each subsequent event. However, examining and documenting the damages the building experienced during earthquakes can contribute to preventing future damages and ensuring the building's sustainability.

The literature emphasizes the following lessons learned from damage assessment and documentation studies in stone buildings: Vlachakis et al. (2017) [6], in the aftermath of the Lesvos Earthquake (Greece), identified that the general damages in stone buildings were primarily due to the inadequacy of structural connections and the weakening of the mortar, which is the construction material, as a result of various factors. One significant factor contributing to earthquake damages was the use of different materials between the double-layered walls in the construction technique of these buildings. Çağlar et al. (2020) [7], in their damage studies in Elâzığ and Malatya (Turkey), found that the reasons for damages in stone buildings were structural and material flaws. Post-earthquake research conducted in various parts of the world consistently highlights that earthquake damages in stone masonry buildings are generally caused by factors such as varying rigidities between double-layered walls, insufficient connections, and material incompatibilities [8-15]. Italy stands as a noteworthy example of lessons learned after earthquakes. The devastating earthquakes that struck Italy in the 1970s and 1980s led to a thorough reevaluation of the effectiveness and compatibility of the restoration techniques previously adopted. As a result of the earthquake events, the performance of previous strengthening techniques was tested, and measures for retrofitting were renewed. Consequently, some previously adopted techniques were restricted or even banned [16-19].

Historical buildings undergo multiple repairs across different periods. However, a review of the literature shows that the reasons why past interventions fail to prevent recurring damage have not been examined in a thorough and systematic manner. Therefore, there is a need for studies that not only describe earthquake-induced damages but also evaluate their underlying causes together with the performance of previous interventions. The purpose of this study is to (I) examine the damages incurred by the structure after earthquakes and present the damage models affecting the stone building, (II) identify the weaknesses and factors leading to damages, and (III) determine why previous post-earthquake repairs failed and emphasize preventive factors. To achieve these objectives, archival research and field studies were conducted.

The main contribution of this research is to demonstrate the “restored parts fail first” phenomenon in repeatedly restored historic masonry structures. The analyses revealed that certain areas subjected to previous restoration interventions experienced earlier and more severe damage during subsequent earthquakes compared to the original parts of the structure. Through a tailored damage classification framework adapted from FEMA 306[40], EMS-98[41] and Vlachakis et al. (2020) [43] along with systematic archival analysis, this study shows that previous restoration interventions not only failed to improve the structural seismic performance but, in many cases, increased the vulnerability of the repaired section.

1.1.CASE STUDY

1.1.1.THE GEOLOGY AND TECTONICS OF THE AREA

There are three major strike-slip faults in the world. Two of these strike-slip faults pass through Turkey. These are the East Anatolian Fault (EAF) and the North Anatolian Fault (NAF), and the third one is the San Andreas Fault. The East Anatolian Fault Zone (EAF) is a deformation belt that starts from Karlıova in Eastern Anatolia and extends towards Antakya with a width of 4-25 km and a length of 580 km. It has been moving for the past 2 million years, causing a lateral displacement of 15 km to date. The slip rate is approximately 8 mm per year. According to historical records, along the EAF, numerous earthquakes with magnitudes ranging from 6.7 to 7.8 have occurred in the mentioned sections, resulting in severe damages [20].

The East Anatolian Fault Line passes approximately 23 km south of Malatya in a straight line. Due to its proximity to the East Anatolian Fault Zone and being located on a fault line close to this zone, Malatya city and its surrounding areas are among the high-risk earthquake zones in Turkey. The city center of Malatya is situated within the first-degree earthquake zone. All the earthquakes that occur in Malatya and its vicinity have a tectonic origin. These earthquakes are associated with the Hazar-Sincik, Çelikhan-Gölbaşı, and Sürgü faults. The Malatya Fault was first identified by Aktimur in 1979, who named it "Malatya Fault" based on aerial photographs [21-23].

The subject of the research, Malatya city, and its surrounding area are located in the Upper Euphrates Region of the East Anatolian Region, south of the basin with the same name. The southern part of the low plateau characteristic Malatya basin is surrounded by the Malatya Mountains, which are extensions of the Southeastern Taurus Mountains, with an average elevation of 2500 meters. The highest point with an elevation of 2545 meters is the Şillan Hill on Mount Beydağı. To the west and north of the basin, there are areas that can generally be considered as high plateau areas, with some structural features but mostly characterized by erosion surfaces as high plateaus. Malatya city has developed in the piedmont plain, which is covered with alluviums sloping gently and regularly from the Beydağları Mountains towards the basin, thickening gradually in the west and northwest directions. The potential damage effect of a possible earthquake depends on local ground conditions, such as variations in the soil properties, vibration characteristics, settlement, groundwater level, and liquefaction susceptibility. The majority of Malatya city center is built on alluvial deposits [24] (see Fig. 1).

1.1.2.HİSTORY AND ARCHİTECTURAL FEATURES OF TEZE CAMİ

The historical landmark, also known as Teze Cami among the locals, was originally built as "Hacı Yusuf Efendi Camii" in 1843. It suffered damage during the Great Malatya Fire in 1889 but was reconstructed with the support of the Ottoman Sultan Abdulhamid II. Over the years, the New Mosque (Teze Cami) has faced numerous earthquakes. It experienced damage during the earthquake of March 3, 1893. In 1913, it underwent repairs, but on June 14, 1964, it was once again damaged by another earthquake. The mosque's dome and walls were restored, and in 2005, it went through a significant restoration process due to another earthquake. Following the Elazig earthquake on January 24, 2020, the dome suffered severe damage, but it was repaired and reopened for worship. However, during the Kahramanmaras earthquake on February 6, 2023, the mosque was almost completely destroyed [26].

Malatya Teze Cami reflects the characteristics of Ottoman architecture with its square plan and a large dome covering the prayer hall supported by four pillars. The entire mosque is constructed from carved stone and consists of a central dome and a prayer hall with five rooms. The last mahfil (gallery) of the mosque is located on an area of 1,500 square meters, with a plan of 24.50 meters by 24.50 meters, and it is 4 meters wide with arcades. The central dome of the mosque is supported by four piers and covered with a suspended central dome, resting on four thick columns and reinforced with barrel vaults and smaller corner domes on each side. The side wings are covered with a central dome and half domes, with smaller similar domes on the corners. The main entrance, providing access to the main prayer hall, is a stone-carved door adorned with geometric and floral motifs. The narthex is 4 meters wide and covered with arcades. Additionally, two round-bodied, two minarets with two balconies each and made of stone materials were added on both sides of the last gallery. In terms of facade architecture, the eastern wall features two windows. The western facade is blind, forming two dome silhouettes in succession with upper coverings. In the middle section of the southern facade, there is a mihrab (prayer niche) within a half-dome, located symmetrically as the central axis of the facade. The mosque and minarets exhibit unique architectural features, which can be the subject of separate research. The minaret's conical capstone, in some earthquakes, has fallen and was replaced with a new one [27].

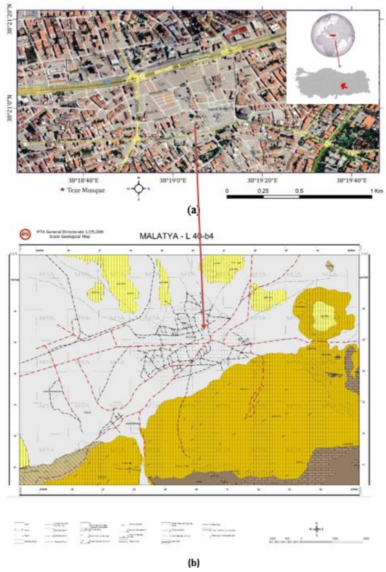


Figure 1. Location of Malatya Teze Mosque (a) and Geological Map (b) [25].

2.METHOD

The research was conducted in two stages: a literature review and archival-based office work. In the first stage, a semi-quantitative damage classification and severity assessment matrix was developed to systematically evaluate the earthquake-induced damages observed in the mosque. The proposed framework is based on typical seismic damage mechanisms commonly encountered in unreinforced masonry (URM) structures, including in-plane and out-of-plane behaviors, connection deficiencies, material deterioration, structural discontinuities, and foundation-related failures. The classification system was primarily developed by adapting the damage types and collapse mechanisms defined in internationally recognized references, particularly FEMA 306 [40] and EMS-98 [41], such as foundation settlement, in-plane and out-of-plane wall failures, roof–wall separation, overturningmechanisms, and connection failures. Furthermore, the element-level structural damage assessment methodology proposed by Vlachakis et al. (2020)[42] following the 2017 Lesvos earthquake provided important analytical guidance for identifying recurring damage patterns and evaluating damage evolution over time. The collected information was adapted to the specific structural, material, and architectural characteristics of historic stone mosques, resulting in a tailored damage classification matrix for these structures. In addition to damage identification, the framework incorporates a measurable damage severity scoring system and a “main cause” evaluation column in order to establish a more systematic and comparative analytical methodology. Unlike conventional descriptive approaches, this semi-quantitative framework enables the comparative assessment of recurring damage patterns observed in different earthquake periods.

The damage severity scoring system was defined as follows:

- 0 = No observed damage
- 1 = Slight damage

- 2 = Moderate damage
- 3 = Severe damage
- 4 = Partial collapse / critical structural failure

In addition, the "Main Cause" column was introduced to identify the dominant structural or material-related factors associated with each damage type, including weak soil conditions, rigidity incompatibilities, inadequate retrofit interventions, weak structural connections, seismic shear stress, and structural instability. Damage severity values and dominant damage causes were assigned through the systematic evaluation of archival photographs, historical documents, restoration reports, post-earthquake visual records, and comparative damage observations. This approach enabled the identification of recurring structural weaknesses and the interpretation of damage evolution over approximately 130 years. Particular attention was given to the recurring vulnerability of previously restored sections. The analyses revealed that some areas subjected to earlier restoration interventions experienced earlier and more severe damage during subsequent earthquakes compared to the original structural components. This phenomenon, defined in this study as "restored parts fail first," constituted one of the principal analytical findings of the research. The developed assessment matrix therefore serves as a practical analytical tool for evaluating post-earthquake damage in historic stone mosques located in different geographical regions (Table 1).

In the second stage, a detailed archival investigation was carried out to analyze the historical earthquake damages sustained by the building. For this purpose, the earthquakes affecting the structure in different years and the corresponding post-earthquake damages were systematically examined. Various archival sources, including newspapers, historical reports, restoration documents, books, magazines, and digital archives, were reviewed. The damage patterns identified for the earthquakes of 1893, 1964, 2020, and 2023 were comparatively evaluated and transferred into the damage classification matrix presented in Table 1. The resulting data were interpreted together with representative historical and post-earthquake photographs. In addition, schematic drawings, comparative damage diagrams, and damage evolution timelines were prepared to facilitate the visualization, comparison, and systematic interpretation of recurring damage mechanisms over time.

Table 1. Damage Classification and Severity Matrix of Teze Mosque) [40,41,42]

Damage Code	**Components**	**Definition**	**1893**	**1964**	**2020**	**2023**	**Main Cause**
(1)	Foundation	Settlement of the foundation soil	2	2	3	3	Weak soil conditions
(2)	Walls	Crumbling or loss of stone walls	0	1	0	0	Material deterioration
		Deterioration of cladding material, especially in double-walled stone structures	0	0	0	2	Rigidity incompatibility in double-leaf walls
		Damage occurring between vertical walls due to different material usage, inadequate connections, previous insufficient retrofit interventions, or lack of maintenance	0	0	2	2	Weak structural connections and inadequate retrofit interventions
		In-plane sliding cracks in the main body of the wall	0	2	0	0	Seismic shear stress

		Shear cracks in the main body of the wall	0	2	0	0	Repeated seismic loading
		Toppling of the entire wall or a part of it out of its plane	0	0	0	4	Out-of-plane instability and connection deficiency
(3)	Columns	In-plane shear cracks in the wall's main body	0	0	0	0	No observed damage
		In-plane torsional or shear cracks	0	0	0	0	No observed damage
		Toppling or collapse	0	0	0	0	No observed damage
(4)	Slabs	Spalling or loss of stone veneer	1	1	0	0	Surface material deterioration
(5)	Dome	Damage occurring at the roof corners or top of the main wall	2	2	3	3	Roof-wall separation and structural discontinuity
		Shear damage between the roof and walls, especially due to previous inadequate strengthening interventions or lack of maintenance	0	0	2	3	Inadequate strengthening interventions
		Roof collapse or settlement of roof elements	0	0	2	3	Structural instability
(6)	Minarets	In-plane sliding cracks	0	2	0	0	Seismic vibration effects
		In-plane torsion or shear cracks	0	2	0	0	Torsional seismic behavior
		Deterioration or loss of stones in stone walls	0	2	0	2	Material weathering and seismic action
		Toppling	2	0	0	4	Slender structural behavior and instability
(7)	Auxiliary Elements (Arch, Decorations, Chimney, Cornices, etc.)	Loss or displacement of auxiliary elements	0	2	2	2	Weak anchorage and vibration effects
		Shear cracks on auxiliary elements	0	0	2	2	Stress concentration during earthquakes

Note: As shown in Table 1, the proposed damage classification and severity scoring system is based on typical seismic damage mechanisms observed in unreinforced masonry (URM) structures. The framework was adapted from FEMA 306 (1998) , EMS-98 (1998), and Vlachakis et al. (2020) [40,41,42] according to the specific structural, material, and architectural characteristics of historic stone mosques. Damage severity values were assigned through archival photograph analysis, historical documentation, and post-earthquake observations using a semi-quantitative evaluation approach.

3.RESULTS

In this section, the damage models and contributing factors observed during the severe earthquakes listed in Table 1 are explained in detail with schematic drawings and photographs.

3.1.THE 3RD OF MARCH 1893 EARTHQUAKE

The earthquake that occurred on 3rd March 1893 took place in the Çelikhan-Gölbaşı segment and had a significant impact over a large area. The earthquake was felt from Aleppo to Sivas and Yozgat, but its most devastating effects were observed in the center of Malatya province. The 1893 earthquake stands out as the most intense and destructive earthquake ever recorded in the region in terms of damage and losses. Due to coinciding with the period of the decline of the Ottoman Empire, there is not much detailed archive available about this major earthquake.

During the 1893 earthquake, the minaret of Malatya Teze Camii suffered a collapse above the balcony level. When the New Mosque (Yeni Cami) was constructed, the minaret was intentionally left unfinished as a memorial to remember the effects of the earthquake. The General Secretary and Historian of Malatya City Council, Abdulkadir Artan, provided some information about the history of the New Mosque and the disasters it experienced, stating the following during a verbal interview: "The minaret with no upper part above the balcony, left by Hocazade Hacı Yusuf Efendi, is a monument of the earthquake. Because you can see the horror of the 1893 earthquake by looking at that minaret" [28] (see Fig. 2).

Figure 2. The original state of the structure and the restoration after the 1893 earthquake, where the minaret was left unfinished as a reminder of the earthquake [28].

3.2.14TH OF JUNE 1964 EARTHQUAKE

On June 14, 1964, a 6.0 magnitude earthquake struck Malatya on a Sunday at approximately 3:15 PM. During this earthquake, the Malatya Teze Cami experienced several damages, including cracks in the dome and some walls. Some of the stones serving as the base for the minarets' finials, acting as a supporting element for the dome, fell off. Due to the historical context of the event, there is not much detailed archival information available regarding the aftermath of this significant earthquake, which coincided with the decline of the Ottoman Empire.

Following the earthquake, the Vakıflar Genel Müdürlüğü (General Directorate of Foundations) undertook restoration efforts to repair the damaged parts of the cami. The upper parts of the window frames were removed, and the damaged areas were repaired. The lead roofing of the cami was replaced, cracks were filled, and the interior plastering was renewed. In addition, the intermediate dome stones were removed, and larger finials were installed on the minarets, giving them a new shape. The frames of the intermediate upper windows were also removed. Furthermore, in response to continuous public demands, the Vakıflar Genel Müdürlüğü carried out a second auction to ornate the interior of the cami, adding decorative elements to the dome and inscriptions on it [29] (see Fig. 3).

Figure 3. Damage and restoration of Malatya Teze Mosque after the 1964 earthquake [29]

3.3.THE 24TH OF JANUARY 2020 ELAZIĞ-MALATYA EARTHQUAKE

The earthquake that occurred on January 24, 2020, centered in Sivrice with a magnitude of 6.8, caused significant damage to the mosque. The main dome partially collapsed, and walls exhibited shear cracks, while the minaret domes experienced crumbling. Based on the available images from the archives, it is believed that the causes of the observed damages are as follows [30].

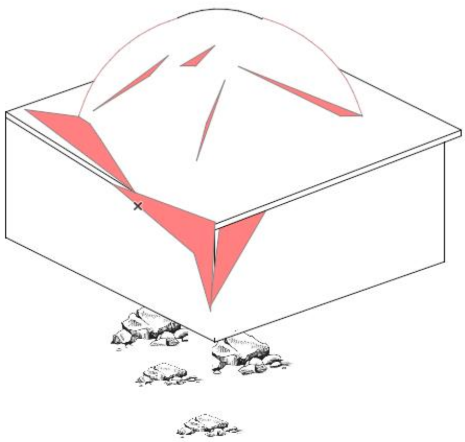


Figure 4. Damage caused by the 24th January 2020 Elâzığ- Malatya earthquake - Schematic drawing of the damage (Damage at the corners of the roof or on the main wall, Roof element displacement, Shear cracks on arches) (Developed by the author, 2026)

The shear cracks observed in the walls occur when the tensile stress at the center of the walls reaches its tensile capacity. This mode of damage is more brittle and appears as cross X-shaped cracks on the wall, particularly in large stone walls. Figure 5 shows example cases of damage patterns resulting from the tensile stress reaching its capacity at the center of the walls (see Figure 5).

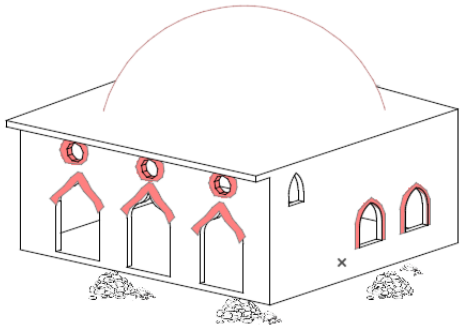


Figure 5. Schematic drawing of the damage (Damage occurring between vertical walls due to different material usage, insufficient connections, previous inadequate reinforcement interventions, or lack of maintenance, Crumbling or loss on corbels) (Developed by the author, 2026)

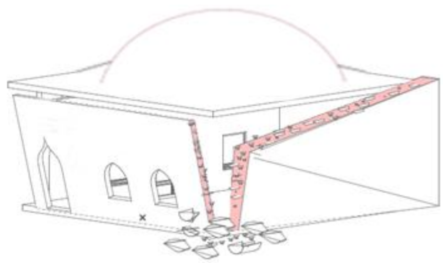
After the earthquake, strengthening works were carried out on the damaged mosque. During these works, the main dome and other damaged domes were completely removed and replaced. Additionally, buttresses were added to the east and west side walls to reinforce the structure. The interior walls of the mosque were also strengthened, and reinforcement was done on the foundation. In newspaper reports after the 2020 earthquake, it was mentioned that the parts of the mosque that were previously restored were the first to collapse. It was stated by various experts that the added buttresses on the east and west walls collapsed, the newly constructed dome completely collapsed, and the restoration efforts proved ineffective and even worsened the damage [30].

3.4.THE EARTHQUAKE CENTERED IN KAHRAMANMARAŞ ON FEBRUARY 6, 2023

After being reopened for worship in 2023 following the 2020 Elâzığ-Malatya earthquake, the structure suffered severe damage again during the 7.7 and 7.6 magnitude earthquakes centered in Kahramanmaraş on February 6. The four minarets, dome, and walls of the building were affected. The dislodging of stones from the walls was prominently observed on the building [30].

The structure has double-walled construction, with the outer and inner wall layers made of different materials. The outer wall layer consists of perfectly cut stones, chosen for their richness and solidity, while the rest of the structure was constructed with rubble stones. This resulted in different rigidity for the two layers during the earthquake. The earthquake forces exerted more impact on the outer wall layer, while the inner wall layer, being more flexible, was less affected. The irregular and non-monolithic nature of the stone walls, coupled with negligible tensile strength and high mass, led to the early occurrence of local failure mechanisms during seismic events.

These local mechanisms were not mitigated through proper construction details and structural connections, leading to partial collapse. The connections between the outer and inner wall layers in the double-walled construction also played a significant role in the partial collapse of the walls. The walls were built using weak binding materials like lime mortar and earth mortar. Earth mortar was mainly used in the inner part of the wall layer and its low binding properties, low compressive strength, and sensitivity to moisture resulted in further weakening of the wall element's rigidity. Additionally, the adverse effects of atmospheric conditions (such as temperature and rainfall) caused deformations in the mortar and joints over time, leading to cracks in the structure during earthquakes. The low-strength properties of the mortar, the use of earth as filling material, and inadequate wall connections contributed to the weakening of the walls and facilitated separations during the earthquake (see Figure 6).



(a)

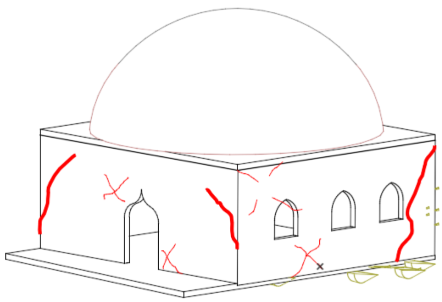
(b)

Figure 6. a) Schematic drawing of the damage (Developed by the author, 2026) (b) Images illustrating the vulnerability created by the joining of different types of materials, such as cut stone and rubble stone, used in double-walled construction, in the presence of earth mortar (The images used in this study were obtained from the following source: AA Haber[30] , Malatyahaber. (2023)[31] and Busabah Malatya (2023) [33].

Another finding is the weak mortar connection in the structure. Mortar material is a crucial component that holds the stone blocks together. It fills the gaps between the stone blocks, providing structural integrity, flexibility, and resilience to the building. During an earthquake, the distribution of horizontal and vertical forces in the structure is significantly influenced by the quality of the mortar. The load-bearing characteristics of the walls depend on factors such as the type of stones used, the quality of the mortar, and the connection details, all of which affect the behavior of the walls during an earthquake.

The emptying of mortar in the masonry of stone structures has several negative effects during earthquakes. It weakens the connections between stone blocks, rendering the structure less resistant to seismic forces, making it more susceptible to collapse or damage. In cases where the mortar is missing or weak, the displacement and sliding of stone blocks during an earthquake are more likely, resulting in structural deformation and cracks in the building. Insufficient strength of connection elements also makes the structure more vulnerable. If the connections are too weak or missing altogether, partial wall displacements and collapses can occur during an earthquake, subjecting the walls to significant loads.

During field inspections, it was observed that natural factors over the years have led to the weakening and erosion of the mortar in the structure. The problem of wall displacement due to weak mortar connections was prevalent in the examined building. The emptying of mortar has compromised the structural integrity of the stone masonry, reducing its resistance to shaking motions, resulting in more extensive damage to the building (see Figure 7) [34].

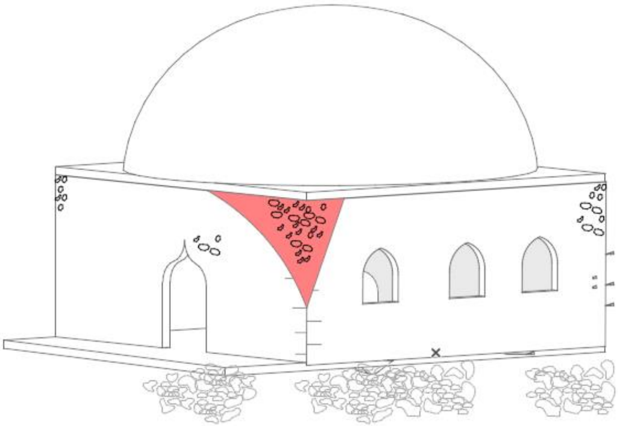


(a)

(b)

Figure 7. a) Schematic drawing of the damage (Developed by the author, 2026) b) Shear cracks in the main body of the wall due to the weakness of the mortar (The images used in this study were obtained from the following source: AA Haber (n.d.)[31]

The lack of horizontal bonding stones in the wall joints of the structure resulted in the detachment of walls and separation of stone surfaces. Adequate bonding capacity is essential in rubble masonry structures, typically achieved through corner stones. Various studies [35-37] emphasize that horizontal bonding stones in stone constructions provide horizontal sliding planes, distribute energy, and enhance the durability of stone walls, thus improving earthquake performance of the buildings. This technique reinforces the horizontal connections between walls, helping to bind the leaves of a wall together and prevent disintegration. The section below illustrates damages caused by the absence of corner connections in the structure (see Figure 8).



(a)

(b)

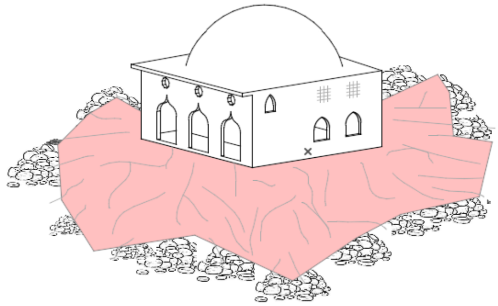
Figure 8. a) Schematic drawing of the damage (Developed by the author, 2026) b) Typical multi-story wall sections with missing horizontal bonded stones and inadequate corner stone connections (The images used in this study were obtained from the following source: AA Haber (n.d.) [31]

The toppling of walls in the corners of the structure is also prevalent in the building. When buildings lack "box-like behavior," meaning that structural elements are not interconnected with unified lateral diagrams, bending occurs in the inertia forces of walls perpendicular to the earthquake effect. Under such effects, the capacity of stone walls significantly decreases, leading to the collapse of many walls in events similar to the Turkey earthquake. Long walls or walls without adequate lateral support undergo vertical, one-way bending. Particularly in the structure, two-way bending is observed, especially in the upper parts of facades with inadequate connection to the roof (see Figure 9).

(a) (b)

Figure 9. a) Schematic drawing of the damage (Developed by the author, 2026) b) Toppling of the entire wall or a portion of it out of the plane (The images used in this study were obtained from the following source: Habername. (2023, March 7)[32]

The foundation on which the stone walls of the structure rely is an important component that provides support to the building. The foundations and ground conditions of stone structures are significant factors that affect the durability of the buildings. An inadequate or low-quality foundation can lead to the collapse and settlement of the upper parts of the walls during earthquakes [4]. Based on archival research regarding the site where the mosque is located, it is reported that the area was known to have weak ground conditions when the mosque was constructed. The 1894 Mamuret-ül-Aziz Salname [38] provides the following information about the foundation: "During the excavation of the mosque's foundation, a substantial amount of water emerged, and juniper trees were used to prevent waterlogging. After the workers drove the piles into the ground, they filled the hole created with a paste-like substance known as 'log'. This suggests that the characteristics of the ground and foundation of the structure may have influenced the potential wall collapses during the earthquake. Further investigation is needed to understand the site conditions, groundwater level, and adequacy of the building's foundation (see Figure 10).



(a)

(b)

Figure 10. a) Schematic drawing of the damage (Developed by the author, 2026) b) Damage images attributed to ground-related issues (The images used in this study were obtained from the following source: Busabah Malatya (2023) [33]

4.DISCUSSION

Over the past 20 years, several earthquakes in Turkey have caused significant loss of life and property. This article explains the geological and geotechnical aspects of the region and the performance of the structure due to earthquakes based on on-site assessments. Through various archival research and field studies, the damages occurred in the Malatya Teze Mosque after the earthquakes in 1893, 1964, 2020, and 2023 have been identified, tabulated, compared, and analyzed. The study reveals enlightening observations about the seismic behavior of the structure after each earthquake. The findings indicate that the repair and restoration efforts carried out after each earthquake did not improve the structural performance for the subsequent earthquake. On the contrary, it was observed that the restored areas were the first ones to suffer damage in the following seismic events. After the earthquakes in 1893, 1964, 2020, and 2023, one of the fundamental causes of the collapse and destruction is attributed to the insufficient support walls and later added buttresses that failed to carry the weight of the dome. As a result, the roof detached from the walls, leading to toppling and collapse. The findings of the study provide evidence that the same damages occur after each earthquake due to these reasons, indicating that the effectiveness of restoration interventions is not thoroughly examined by experts. The factors identified as generally causing damage in the structure after severe earthquakes, excluding aftershocks, include different rigidities caused by double-layered walls, inadequate connections, the use of weak bonding materials, the combination of weak and low-strength materials, and the properties of the ground.

According to observations, almost all the deficiencies encountered in the examinations after earthquakes in our country were also observed in this earthquake region. The material strength of the constructed mortar structures was found to be insufficient, and at the same time, it was observed that the structural elements were not well locked at the connection points of the mortar structures. Çağlar et al. (2020) [7] determined in their damage studies in Elâzığ and Malatya that the reasons for the damage in stone structures were structural and material defects. Teze Cami also showed the occurrence of the same type of damage after each earthquake, and this study has similar results. Similarly, Vlachakis et al. (2017) [6] identified the cause of stone structure damages in the Lesvos Earthquake (Greece) as the inadequacy of structural connections and the weakening of mortar, the construction material, due to various factors. These findings are consistent with our study findings. One significant factor contributing to the formation of earthquake damage in structures is the use of different materials between the double-layered walls present in the construction technique. The study results are similar to research findings conducted in various locations around the world after earthquakes, indicating that the general causes of damage in stone structures after earthquakes in Turkey are mainly due to the different rigidities caused by double-layered walls, inadequate connections, the use of weak bonding materials, and the combination of weak and low-strength materials [8-15]. As a result, it has been determined that the effects of earthquakes on Teze Mosque are related to the construction technique, seismic behavior, mismatched materials, inadequate connection elements, and weak mortar. Additionally, geotechnical factors such as soil conditions need to be considered.

5.CONCLUSION

One of the most significant findings of this study is that sections subjected to previous restoration interventions became the most vulnerable parts of the structure during subsequent earthquakes. Comparative analyses revealed that damage initiated earlier and progressed more severely in previously restored wall junctions, roof–wall connections, and minaret elements compared to the original structural fabric. This finding indicates that restoration practices focused solely on repairing visible damage are insufficient for ensuring the long-term seismic resilience of historic masonry structures.

Based on the findings of this research, the following conclusions and lessons can be drawn:

(I) Malatya is located in the impact zone of the East Anatolian Fault (EAF), one of the most active faults in the world. Therefore, improving foundation stability and considering local soil conditions are essential before any restoration work. A detailed geotechnical investigation should be conducted prior to restoration, and appropriate ground improvement techniques — such as epoxy grouting or soil consolidation — should be implemented to enhance the foundation's performance.

(II) The stone walls of the Teze Mosque are highly susceptible to damage mechanisms such as partial collapse, settlement, and out-of-plane overturning during earthquakes. These damages are primarily caused by insufficient connections between structural elements, the double-leaf wall system with differing rigidities, and the use of weak bonding mortars (lime and earth mortar). The absence of adequate cornerstones and through-stones further contributes to wall separation and disintegration. To mitigate these issues, proper structural connections, compatible materials, and enhanced wall interlocking details should be employed in future interventions.

(III) Long-term environmental effects have significantly weakened and eroded the mortar in the masonry over time. Before any restoration, a detailed characterization of the existing mortar is necessary to understand its mechanical properties and compatibility with new materials. This step is crucial for achieving durable and seismically compatible repairs.

The phenomenon defined in this study as "restored parts fail first" clearly shows that post-earthquake interventions in historic masonry structures should move beyond mere damage repair toward a comprehensive, performance-based conservation approach that prioritizes material compatibility, structural integrity, and long-term seismic behavior.

Acknowledgments and Information Note

An earlier version of this study was presented as an abstract at the IV. International Architectural Sciences

& Applications Symposium (IArCSAS 2024), held in Girne, Cyprus [39]. The authors would like to thank the symposium organizers and participants for their valuable feedback and contributions, which helped improve this paper.

REFERENCES

[1] Caglar, N., Vural, I., Kirtel, O., Saribiyik, A., & Sumer, Y. (2023). Structural damages observed in buildings after the January 24, 2020 Elazığ-Sivrice earthquake in Türkiye. *Case Studies in Construction Materials, 18*, Article e01886.

[2] AFAD (T.C. İçişleri Bakanlığı Afet ve Acil Durum Yönetimi Başkanlığı). (2023). *06 Şubat 2023 Pazarcık (Kahramanmaraş) Mw 7.7 Elbistan (Kahramanmaraş) Mw 7.6 depremlerine ilişkin ön değerlendirme raporu*. https://deprem.afad.gov.tr/assets/pdf/Kahramanmaras%20%20Depremleri_%20On%20Degerlendirme%20Raporu.pdf

[3] TMMOB Mimarlar Odası 6 Şubat 2023 Depremleri Tespit ve Değerlendirme Heyeti. (2023). *Depremde zarar gören kültür varlıklarının güncel durumu ve akıbeti*. https://argonotlar.com/depremde-zarar-goren-kultur-varliklarinin-guncel-durumu-ve-akibeti

[4] Chen, B., Yu, Z., Li, L., Zheng, R., & Wu, C. (2023). Surface deformation and damage of 2022 (M 6.8) Luding earthquake in China and its tectonic implications. *Open Geosciences, 15*(1), Article 20220490. https://doi.org/10.1515/geo-2022-0490

[5] Yang, X., Xie, Z., Ling, F., Luo, X., & Zhong, M. (2016). Post-earthquake people loss evaluation based on seismic multi-level hybrid grid: A case study on Yushu Ms 7.1 earthquake in China. *Open Geosciences, 8*(1), 639–649.https://doi.org/10.1515/geo-2016-0051

[6] Vlachakis, G., Vlachaki, E., & Lourenço, P. B. (2020). Learning from failure: Damage and failure of masonry structures, after the 2017 Lesvos earthquake (Greece). *Engineering Failure Analysis*. Volume 117. https://doi.org/10.1016/j.engfailanal.2020.104803

[7] Coïsson, E., Ferretti, D., & Lenticchia, E. (2017). Analysis of damage mechanisms suffered by Italian fortified buildings hit by earthquakes in the last 40 years. *Bulletin of Earthquake Engineering, 15*, 5139–5166.

[8] Sisti, R., Di Ludovico, M., Borri, A., & Prota, A. (2019). Damage assessment and the effectiveness of prevention: The response of ordinary unreinforced masonry buildings in Norcia during the Central Italy 2016–2017 seismic sequence. *Bulletin of Earthquake Engineering, 17(10)*, 5609–5629. https://doi.org/10.1007/s10518-018-0448-z

[9] Penazzi, D., Binda, L., Valluzzi, M. R., Cardani, G., Baronio, G., & Modena, C. (2000). Behaviour of historic masonry buildings in seismic areas: Lessons learned from the Umbria Marche earthquake. In *Proceedings of the 12th International Brick/Block Masonry Conference* (pp. 217–235). Madrid, Spain.

[10] Sorrentino, L., Cattari, S., da Porto, F., Magenes, G., & Penna, A. (2019). Seismic behaviour of ordinary masonry buildings during the 2016 central Italy earthquakes. *Bulletin of Earthquake Engineering, 17*, 5583–5607. https://doi.org/10.1007/s10518-018-0370-4

[11] Augenti, N., & Parisi, F. (2010). Learning from construction failures due to the 2009 L'Aquila, Italy, earthquake. *Journal of Performance of Constructed Facilities, 24*(6), 536–555. https://doi.org/10.1061/(ASCE)CF.1943-5509.0000122

[12] Javed, M.,Khan, A. & Penna, A. & Magenes, G. (2006). Behaviour of masonry structures during the Kashmir 2005 earthquake. First European Conference on Earthquake Engineering and Seismology (1st ECEES), Geneva, Switzerland, paper. 1077.

[13] Ingham, J., & Griffith, M. (2010). Performance of Unreinforced Masonry Buildings During the 2010 Darfield (Christchurch, Nz) Earthquake. *Australian Journal of Structural Engineering, 11*(3), 207–224. https://doi.org/10.1080/13287982.2010.11465067.

[14] Senaldi, I., Magenes, G., & Ingham, J. M. (2015). Damage Assessment of Unreinforced Stone Masonry Buildings After the 2010–2011 Canterbury Earthquakes. *International Journal of Architectural*

Heritage, *9*(5), 605–627. https://doi.org/10.1080/15583058.2013.840688

[15] Bruneau, M. (1994). State-of-the-art report on seismic performance of unreinforced masonry buildings. *Journal of Structural Engineering, 120*(1), 230–251. https://doi.org/10.1061/(ASCE)0733-9445(1994)120:1(230)

[16] Türkeri, İ. (2022). Dinî Mimaride Doğal Taş Kullanimi: Sancaklar Camii Ve Beylikdüzü Fatma Ana Cemevi. *Tasarım Mimarlık ve Mühendislik Dergisi, 2*(1), 1-9. https://izlik.org/JA84JZ85NF

[17] Karataş, L., & Dal, M. (2023). A Graphical Ontology-Based Method for Rapid Damage Assessment of Stone Cultural Heritage Structures After an Earthquake: A Case Study of Mor Petrus and Mor Paulus Church, Adıyaman/Türkiye. *Journal of Architectural Sciences and Applications, 8*(Special Issue), 222-240. https://doi.org/10.30785/mbud.1310031

[18] Karataş, L. & Bayhan, B. (2023). Damage assessment and restoration proposal following the 2023 Türkiye earthquakes: UNESCO World Heritage Site Diyarbakır City Walls, Türkiye, *Heritage Sci*ence, 11, 228. https://doi.org/10.1186/s40494-023-01072-6

[19] Sorrentino, L., Cattari, S., da Porto, F., Magenes,G. & Penna,A.(2019). Seismic behaviour of ordinary masonry buildings during the 2016 central Italy earthquakes. *Bulletin of Earthquake Engineering*, 17, 5583–5607 https://doi.org/10.1007/s10518-018-0370-4

[20] TMMOB Jeoloji Mühendisleri Odası. (2004). *Malatya'nın jeolojisi, depremselliği ve maden potansiyeli sempozyumu sonuç bildirgesi*. https://www.jmo.org.tr/resimler/ekler/bae5f81d1c4563a_ek.pdf?dergi=HABER%20B%DCLTEN%DD

[21] Karadoğan, S. (2007). *Malatya kenti ve yakın çevresi için olası doğal riskler ve afet yönetimi (GIS ortamında örnek bir uygulama)*. https://web.itu.edu.tr/tahsin/CBS2007/sunu/60.pdf

[22] Karadoğan, S. (1994). *Kuruluş yeri açısından Malatya şehri ve yakın çevresinin jeomorfolojisi*, Yüksek lisans tezi, Fırat Üniversitesi, Sosyal Bilimler Enstitüsü.

[23] Karadoğan, S., & Özdemir, M. A. (2002). Malatya şehri doğusunda jeomorfolojik özelliklerden kaynaklanan sorunlar. *Fırat Üniversitesi Sosyal Bilimler Dergisi, 12*(2), 31–46.

[24] Önal, M., & Kaya, M. (2007). Stratigraphy and tectono-sedimentary evolution of the Upper Cretaceous–Tertiary sequence in the southern part of the Malatya Basin, East Anatolia, Turkey. *Journal of Asian Earth Sciences, 29*(5-6), 878–890. https://doi.org/10.1016/j.jseaes.2006.06.004

[25] MTA. (2023). *Malatya - L 40 paftasına ait 1/100.000 ölçekli jeoloji haritası*. https://www.mta.gov.tr

[26] Yalvaç, C. (2022, June 12). Hacı Yusuf Camisi- Taş Cami- Teze Cami- Yeni Cami. *Malatyahaber.com*. https://malatyahaber.com.tr/haci-yusuf-camisi-tas-cami-teze-cami-yeni-cami/

[27] Satılmış, S. (2021). Osmanlı Devleti'nde Afet Yönetimine Bir Örnek: 1889 ve 1890 Malatya Yangınları. *Osmanlı Medeniyeti Araştırmaları Dergisi*, *13,* 101-128. https://doi.org/10.21021/osmed.978876

[28] Satılmış, S. (2016). 1893 Malatya Depremi ve afet yönetimi. *OTAM Ankara Üniversitesi Osmanlı Tarihi Araştırma ve Uygulama Merkezi Dergisi*, *39*, 137-177. https://izlik.org/JA27NF96CW

[29] Malatya Söz. (n.d.). Yeni Cami aslını aratmayacak. https://malatyasonsoz.com.tr/haber/15700077/yeni-cami-aslini-aratmayacak

[30] AA Haber. (n.d.). Kaderi depremlerle örülen Teze Cami, asrın felaketine dayanamadı. https://www.aa.com.tr/tr/asrin-felaketi/kaderi-depremlerle-orulen-teze-cami-asrin-felaketine-dayanamadi/2839193

[31] Malatyahaber. (2023). *Teze cami 180 yılda 3 kez depremde hasar gördü*. https://malatyahaber.com/haber/teze-cami-180-yilda-3-kez-depremde-hasar-gordu

[32] Habername. (2023, March 7). *Kaderi depremlerle örülen Teze Cami asrın felaketine dayanamadı*. https://www.habername.com/haber-kaderi-depremlerle-orulen-teze-cami-asrin-felaketine-dayanamadi-180890.htm

[33] Busabah Malatya. (2023). *Yeni cami yıkılmış olabilir ama Malatyalılar için asla… Teze cami halen ayakta*. https://www.busabahmalatya.com/haber/17507724/yeni-cami-yikilmis-olabilir-ama-malatyalilar-icin-asla-teze-cami-halen-ayakta

[34] Mirabile Gattia, D., Roselli, G., AlShawa, O., Cinaglia, P., Di Girolami, G., Francola, C., Persia, F., Petrucci, E., Piloni, R., Scognamiglio, F., Sorrentino, L., Zamponi, S. & Liberatore, D. (2019). Characterization of Historical Masonry Mortar from Sites Damaged During the Central Italy 2016-2017 Seismic Sequence: The Case Study of Arquata Del Tronto. *Ann. Geophys.*, *62* (3), SE341. https://doi.org/10.4401/ag-8019.
[35] Decanini, L., De Sortis, A., Goretti, A., Langenbach, R., Mollaioli, F., & Rasulo, A. (2004). Performance of masonry buildings during the 2002 Molise, Italy, earthquake. *Earthquake Spectra, 20*(1), 191–220. https://doi.org/10.1193/1.1765106
[36] Senaldi, I., Magenes, G., & Ingham, J. M. (2015). Damage Assessment of Unreinforced Stone Masonry Buildings After the 2010–2011 Canterbury Earthquakes. *International Journal of Architectural Heritage, 9*(5), 605–627. https://doi.org/10.1080/15583058.2013.840688
[37] Aras, F., & Düzci, E. (2018). Seismic performance of traditional stone masonry dwellings under Çanakkale seismic sequences. *Journal of Performance of Constructed Facilities, 32*(4). https://doi.org/10.1061/(ASCE)CF.1943-5509.0001173
[38] Vilayet of Ma'muretül'aziz. (1991). *Redhouse yeni Türkçe-İngilizce sözlük* (12th ed.). Redhouse Yayınevi.
[39] Karataş Billor, L. (2024). Documentation of earthquake damages over the years and restoration recommendations for the historic Malatya Teze Mosque. IV. International Architectural Sciences & Applications Symposium (IArCSAS 2024), Girne, Cyprus.
[40] Federal Emergency Management Agency (FEMA). (1998). *Evaluation of earthquake damaged concrete and masonry wall buildings* (FEMA 306). Washington, DC: FEMA. https://www.atcouncil.org/files/FEMA306.pdf
[41] Grünthal, G. (Ed.). (1998). *European Macroseismic Scale 1998* (EMS-98). European Seismological Commission. https://media.gfz.de/gfz/sec26/resources/documents/PDF/EMS-98_Original_englisch.pdf
[42] Vlachakis, G., Vlachaki, E., & Lourenço, P. B. (2020). Learning from failure: Damage and failure of masonry structures, after the 2017 Lesvos earthquake (Greece). Engineering Failure Analysis, 117, 104803. 10.1016/j.engfailanal.2020.104803

Lale KARATAŞ BİLLOR, Asst.Prof.Dr., Architect.
Lale Karataş Billor received her BSc degree in Architecture and completed her MSc and PhD studies in the field of Architecture at Bursa Uludağ University. She completed her PhD dissertation on a metaverse-based instructional design proposal for building materials education in departments of architectural restoration. She is currently serving as an Assistant Professor in the Department of Architecture at Bursa Technical University. Her research interests include architectural restoration, cultural heritage conservation, seismic vulnerability assessment of historic masonry structures, digital heritage documentation, artificial intelligence applications in heritage studies, photogrammetry, LiDAR, UAV-based documentation, and immersive virtual reality environments. Her recent studies particularly focus on the representation of cultural memory, sustainable conservation strategies for historic buildings, and AI-assisted analytical methods in heritage research. She has actively participated in interdisciplinary national and international research projects and has published numerous articles, conference papers, and book chapters on cultural heritage, conservation technologies, and digital representation methods.