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# Architectural Heritage After the February 6th Kahramanmaraş Earthquakes: Preliminary Observations on Historical Masonry Structures

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## 6 Şubat Kahramanmaraş Depremleri Sonrası Mimari Miras: Tarihi Yığma Yapılar Üzerine Ön Gözlemler

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**Abstract**

On February 6th, 2023, Kahramanmaraş province in Türkiye experienced a powerful earthquake with a magnitude of 7.7 on the Richter scale, followed by another significant earthquake with a magnitude of 7.6. These seismic events resulted in considerable loss of life, injuries, and extensive damage to the region's historical masonry structures. The seismic vulnerability of these structures, stemming from factors such as low strength, inadequate seismic detailing, and limited ductility, contributed to various forms of damage, including cracking, displacement, and, in some cases, complete collapse under the seismic forces. The objective of this study is to provide comprehensive field research results of masonry historical structures situated in various cities within the region impacted by the Kahramanmaraş earthquakes occurred on February 6, 2023. The paper presents the findings of reconnaissance studies, delving into the failure mechanisms observed in masonry historical structures, with specific attention to walls, domes, and minarets. The insights gained from the earthquake damages will be valuable in reducing the likelihood of future earthquake damage to these structures.

***Keywords:*** *Kahramanmaraş Earthquakes; Historical Structures; Masonry; Damage.*

**Öz**

2023 yılı 6 Şubat tarihinde, Türkiye'nin Kahramanmaraş ilinde Richter ölçeğine göre 7.7 büyüklüğünde şiddetli bir deprem meydana gelmiş, ardından 7.6 büyüklüğünde bir başka büyük deprem daha yaşanmıştır. Bu sismik olaylar, çok sayıda can kaybı ve yaralanmalara ve bölgedeki tarihi yığma yapılarda geniş çaplı hasarlara neden olmuştur. Bu yapıların düşük dayanım, yetersiz sismik detaylandırma ve sınırlı süneklik gibi etkenlerden kaynaklanan sismik zayıflıkları, çatlama, yer değiştirme ve bazı durumlarda tamamen yıkılma gibi çeşitli hasar türlerine yol açmıştır. Bu çalışmanın amacı, 6 Şubat 2023 Kahramanmaraş depremlerinden etkilenen bölgedeki çeşitli şehirlerde bulunan yığma tarihi yapıların kapsamlı saha araştırması sonuçlarını sunmaktır. Makale, yığma tarihi yapılarda gözlemlenen hasar mekanizmalarını, özellikle duvarlar, kubbeler ve minareler üzerindeki etkilerini inceleyen keşif çalışmalarının bulgularını paylaşmaktadır. Deprem hasarlarından elde edilen bu çıkarımlar, gelecekte bu tür yapıların deprem hasarlarını azaltmada önemli katkılar sağlayacaktır.

***Anahtar Kelimeler:*** *Kahramanmaraş Depremleri; Tarihi Yapılar; Yığma Yapılar; Hasar.*

## 1. Introduction

On February 6th, 2023, a magnitude 7.8 earthquake reported by USGS and 7.7 reported by AFAD struck Pazarcık, Kahramanmaraş, followed by a magnitude 6.7 aftershock just 11 minutes later. Later that day, a particularly strong earthquake with a magnitude of 7.5 by USGS (and reported 7.6 by AFAD) occurred 95 km (~60 miles) to the north. These two large earthquakes were relatively shallow, resulting in severe shaking. The Turkish Accelerometric Database and Analysis System (TADAS, 2023) managed by AFAD (Disaster and Emergency Management Presidency) published all seismic records after the earthquakes. In Figure 1, the epicentres of the Pazarcık and Elbistan earthquakes are marked with black pins with the aftershocks recorded during February 2023. The variable "d" represents the depth of the earthquakes, while "M" indicates their magnitude. The seismic sequence, resulting from shallow strike-slip faulting, caused widespread destruction and resulted in tens of thousands of fatalities in Türkiye and Syria. Official reports confirm that 50,783 people lost their lives in the 2023 Kahramanmaraş earthquakes (Kazaz et al., 2024).

Various studies have been conducted to date focusing on the 2023 Kahramanmaraş earthquakes. Field reconnaissance investigations have been carried out by numerous researchers (Ağvın et al. 2024, Işık et al. 2024, Ivanov and Chow 2023, Karasın 2023, Kocakaplan Sezgin et al. 2024). The literature also includes analyses of

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damages to different structural types beyond masonry structures (Yuzbaşı 2024, İzol et al. 2024, Arslan et al. 2024, Vuran et al. 2024). Furthermore, studies addressing earthquake characteristics and geotechnical damages have been conducted (Çetin et al. 2024, Akar et al. 2024, Öser et al. 2024, Kocakaplan Sezgin et al. 2024).

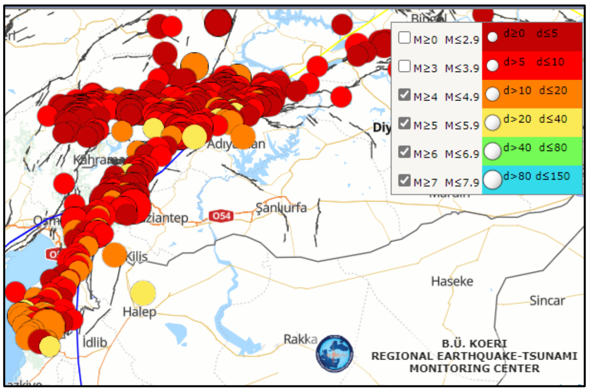


**Figure 1.** Map of 2023 Türkiye earthquake modified from KOERI (KOERI-RETMC, 2023)

Türkiye's historical masonry structures, such as churches, castles, and walls, are an essential part of the country's cultural heritage. The regions affected by the earthquakes including Adana, Adıyaman, Kahramanmaraş, Gaziantep, Şanlıurfa, Diyarbakır, Osmaniye, Hatay, Kilis, Malatya and Elazığ contains a significant amount of cultural heritage. For instance, the UNESCO World Heritage List in 1987 included 'Nemrut Dağ' in Adıyaman. The mausoleum of Antiochus I (69–34 B.C.) located in Nemrut Dag, is regarded as one of the most ambitious constructions of the Hellenistic period. While there is no damage to the archaeological findings on Nemrut Dag, one of the four columns of the Karakuş Tumulus (69–34 B.C.), located at the foothills of Nemrut Dag, was collapsed (ArkeolojiSanat, 2023) proving the destructiveness of the earthquake in the region (see Figure 2). Adana's architectural landscape features, historical landmarks dating back to the Ottoman, Roman, and Byzantine periods. On the other hand, in Kahramanmaraş, the region's earliest known civilization traces back to the Hittites (2000-1200 BC). Gaziantep's recognized 'Gaziantep Castle' dates to the Hittites, and its historic centre reflects Ottoman heritage. Şanlıurfa, recognized for 'Göbekli Tepe,' features cultural gems like the Grand Mosque. Hatay, an ancient Anatolian centre, showcases structures from various eras. Malatya, in the northeast, has a rich history since 5000 B.C., with the 'Yeni Mosque' standing as a notable Ottoman-era symbol.

The present study has two objectives: to present the structural damage and failure patterns induced by Kahramanmaraş earthquake sequences to the historical masonry structures in the region; to highlight the causes and weakness that led to damage, or factors to prevented it. The insights gained from the earthquake damages will be valuable in reducing the likelihood of future earthquake damage to these structures. In pursuit of this objective, the first author conducted a field reconnaissance in the area affected by the Kahramanmaraş earthquakes between February 16 and 24 specifically in Hatay and Gaziantep.

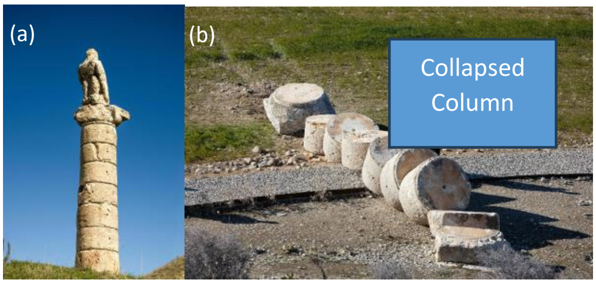


**Figure 2.** Karakuş Tumulus (a) Eagle column (ArkeolojiSanat, 2023) (b) collapsed column.

Due to safety concerns the inspection of most buildings was carried out from the outside. Observations and comments are accompanied by representative photos, while simplified sketches are provided to aid in the interpretation and systematization of the observations. Therefore, this study provides a clear comparison of conditions before and after seismic events, highlighting the critical importance of implementing effective seismic safety measures in the design, construction, and preservation of historical masonry structures. Additionally, drawing lessons from past earthquakes and applying this knowledge to mitigate future risks will enhance community resilience and reduce the potential for disasters.

The subsequent sections of this paper are organized as follows: Initially, recorded strong ground motions and their properties are presented. In the next section, the construction typology of the region is summarized. Following that, the paper presents the findings of reconnaissance studies, delving into the failure mechanisms observed in masonry historical structures, with specific attention to walls, domes, and minarets and concludes with final remarks.

## 2. Seismicity of Türkiye and Recorded Strong Ground Motions during the 2023 Kahramanmaraş Earthquakes

Türkiye is prone to significant seismic activity due to its location on several active faults, including the North Anatolian Fault (NAF), East Anatolian Fault (EAF), Northeast Anatolian Fault (NEAF), and West Anatolian Fault (WAF). The NAF and EAF, known for their frequent seismic activity, have caused numerous major earthquakes in recent decades, resulting in significant casualties and extensive damage. The Kahramanmaraş region, specifically, experiences seismic activity related to the EAF, a significant left-lateral strike-slip fault stretching over 600 km.

The mainshocks and aftershocks of the February Kahramanmaraş Earthquakes were recorded at multiple sites, with the furthest being 460 km from the epicentre. These seismic records were obtained from the Turkish Accelerometric Database and Analysis System (TADAS, 2023). In this study, for the Pazarcık Earthquake, the selected stations were located within a 200 km radius of the epicentre, while for the Elbistan Earthquake, the analysed stations were within 150 km of the epicentre. Figure 3 to Figure 6 illustrates the distribution of Spectral Acceleration (Sa) (1.0 and 0.2) and Peak Ground Acceleration (PGA) values for the Elbistan and Pazarcık Earthquakes and simple faults as well as surface rupture lines (Reitman et al., 2023). the maps were created using ArcGIS software (ESRI, 2011).

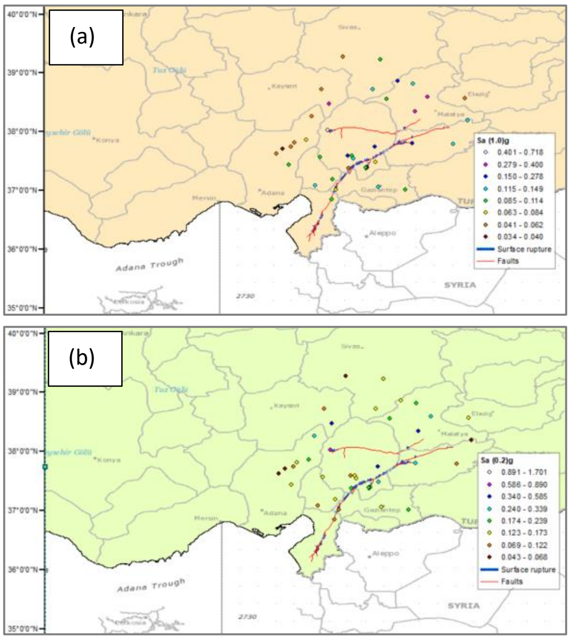


**Figure 3**. Spatial distribution of Spectral acceleration for (a) 1.0g and (b) 0.2g for Elbistan earthquake.

PGA is a direct measure of the maximum horizontal acceleration experienced by the ground during an earthquake and it serves as a critical factor in assessing potential damage to structures. By analysing the PGA values for both Pazarcık and Elbistan earthquakes, we can observe the intensity of shaking experienced in different regions and how this correlates with the earthquake magnitudes. For both earthquakes, PGA distribution shows high values near the epicentre, suggesting localized severe ground shaking. The PGA values tend to decrease as we move further away from the epicentre, though the reduction is not uniform due to geological variations such as soil type and fault characteristics. In some regions, the shaking remained intense due to amplification effects, particularly in areas with softer soil. Spectral Acceleration (Sa) is an important measure used in seismic design to estimate how a structure will respond to different frequencies of ground motion.

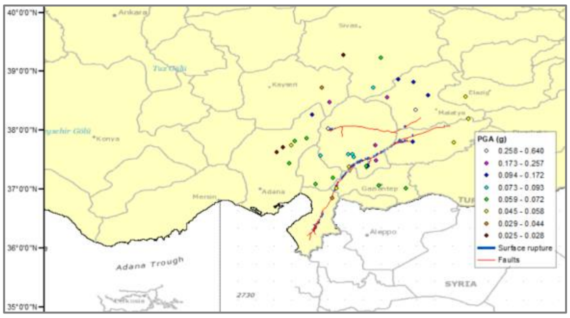


**Figure 4.** Spatial distribution of PGA values for Elbistan Earthquake.

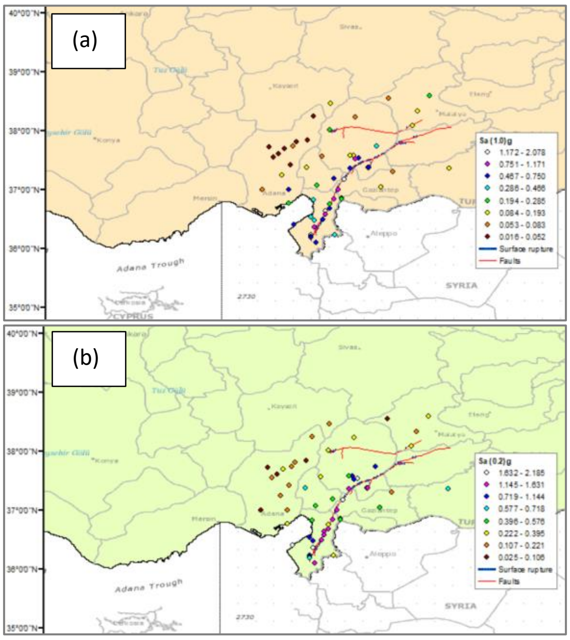


**Figure 5**. Spatial distribution of Spectral acceleration for (a) 1.0g and (b) 0.2g for Pazarcık earthquake.

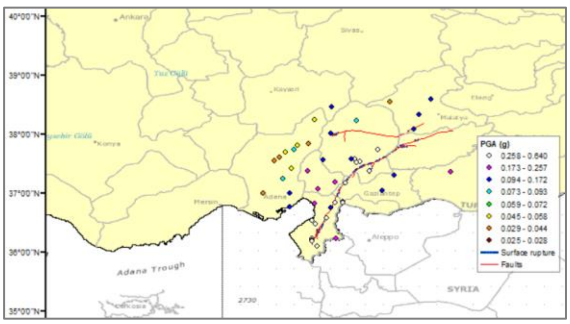


**Figure 6.** Spatial distribution of PGA values for Pazarcık Earthquake.

The Sa(0.1) values taper off less gradually than the PGA values, implying that the shaking affected a broader region, not just limited to the epicentral area. This is critical for low-rise buildings that were subjected to extended periods of high intensity shaking. For the Pazarcık Earthquake the Sa (0.2) distribution shows a similar pattern to Sa(0.1) but with slightly lower peak values near the epicenter, often in the range of 0.8-0.9g while it is in the range of 0.7-0.8g of Elbistan Earthquake. The distribution pattern of Sa (0.1) for the Elbistan event shows a more localized effect, with higher values concentrated closer to the fault rupture zone. The distribution of PGA and Sa (0.1) and Sa(0.2) for the Pazarcık and Elbistan earthquakes reveals significant ground shaking across the affected regions. The Pazarcık event exhibited higher peak values, probably leading to more severe localized damage, while Elbistan showed a wider spread of shaking intensity. Both earthquakes had substantial impact, but the differences in magnitude and location resulted in varying damage potentials.

**3. Varieties of Building Constructions**

The historical structures in the earthquake affected region, encompassing mosques, churches, buildings, mausoleums, and castles, are predominantly constructed using stone masonry and less frequently of brick masonry. Most of these structures were constructed during the Seljuk and Ottoman eras and have been impacted by previous earthquakes and the predominant materials for roofing and flooring systems in these structures are timber. The masonary structures in Türkiye has been affected by the different earthquakes during their lifetime. Many studies have been published up to this time considering the weak behaviour of masonary buildings under several occurred earthquakes in Türkiye (Cetin et al. 2020, Oyguc and Oyguc 2017, Cakir et al. 2015, Dogan et al. 2013).

The subsequent paragraphs provide a summary of the construction materials and techniques identified in these structures, emphasizing structural aspects that significantly influenced the seismic response of the structures.

***3.1 Construction Materials***

The construction materials that were used for the historical structures in the earthquake affected region mostly consist of rubble stone and cut stone. The substandard quality of both the stones and mortar, compounded by degradation over time, has led to poor seismic performance. An illustration of stone disintegration is evident in Figure 7a, representing the Latin Catholic Church of Iskenderun constructed around 1858. Similar failures for the historical masonry structures due to poor quality of material were observed in Samos Island (Aegean Sea) Earthquake with Mw= 7.0 on 30 October 2020 (Cetin et al. 2020) and Mw=6.3 earthquake occurred in Lesvos Island on the 12th of June 2017 (Vlachakis et al. 2020).

The use of cut stones is another widely utilized construction method and material. The stones forming the cut stone wall are generally quarry stones. In the production of cut stone walls, just like alongside traditional structures, stones that are most abundant in their regions and naturally more economical were used in construction. The depth of the stones to be used is arranged to provide the wall thickness. The construction of cut stone walls can be with the use of mortar in between or without any joints. In the construction of jointless cut stone walls, the stones should be connected to each other using connectors of metal (iron or copper). Figure 7b demonstrates the failure of the minaret of the Şirvani Mosque in the city centre of Gaziantep, which was constructed using cut stone (Tayla, 2007). In addition to the slenderness of the minaret, the opened metal connecters in between the stones observed during the field reconnaissance.


**Figure 7.** (a) Rubble stone masonry disintegration due to poor quality of materials, (b) cut stone disintegration due to opened metal connecter equipment in between**.**

***3.2 Construction Techniques***

Unreinforced masonry (URM) refers to structures lacking reinforcement (mainly timber elements) or possessing insufficient reinforcement. Analyses conducted on the damage sustained by buildings in the aftermath of various earthquakes have exposed the seismic vulnerability inherent in URMs (Cetin et al. 2020, Oyguc and Oyguc 2017, Vlachakis et al. 2020, Karatas and Bayhan 2023, Nasery et al. 2024). URM buildings can be built with two- or three-leaf rubble stone masonry (Vlachakis et al. 2020). Figure 8a depicts the Church of Mary in Samandağ, Hatay, which suffered damage due to the absence of transversal interlocking stones, resulting in masonry delamination. It is noteworthy that the Church of Mary sustained minor damage after the earthquakes on February 6th but experienced severe damage following the Samandağ aftershock on February 20, 2023, with a magnitude of 5.8.(Anadolu Ajansı, 2023).

(a) (b)

**Figure 8.** Poor quality, multi-leaves stone masonry buildings (a) Church of Mary, Samandağ, Hatay (Anadolu Ajansı, 2023), (b) English Protestant School, Samandağ, Hatay (Haber Global, 2023).

(a) (b)

**Figure 9.** (a) Proper connection of quoin stones, Karagöz Mosque, Gaziantep. (b) Insufficient connection of quoin stones, St. Nicholas Orthodox Church of Iskenderun, Hatay.

(a) (b)

**Figure 10.** (a) Kahramanmaraş Saraçhane Mosque before the earthquakes (Go Turkiye, 2020). (b) Damage after the Kahramanmaraş earthquakes.

Figure 8b illustrates another example of the damage to a two-leaf stone masonry building corresponding to English Protestant School in Samandağ, Hatay. An important detail in the construction of URM structures is the corners. Typically, corners are constructed using quoin stones, facilitating the connection of transversal walls, and mitigating the risk of local or global failures (Vlachakis et al. 2020). Figure 9a provides a tangible example of the implementation of quoin stones at the Karagöz Mosque in the city centre of Gaziantep, while Figure 9b illustrates the lack of quoin stones in the corner of the St. Nicholas Orthodox Church of Iskenderun in Hatay. The corners of URM buildings during the restoration process should be provided with rigid corner connections to prevent separations or cracks. In timber-laced masonry, vertical and horizontal reinforcing timber bars enhance the strength and ductility of the walls (Oyguc and Oyguc 2017). Figure 10a and 10b exemplify a timber-laced masonry structure, the Kahramanmaraş Saraçhane Mosque, constructed in the 18th century.

The mosque features regularly spaced timber ring elements across the height of the walls. The structure's roof is comprised of timber framing, which collapsed during the Kahramanmaraş earthquakes. However, the timber-laced masonary part of the mosque remains intact. The restoration efforts should be performed carefully not only for the architectural aspects also for the civil engineering concepts based on the seismic design codes (Güleç, 2023).

### 4. Damage and Failure Patterns

Masonry structures, constructed with materials like bricks, stones, and mortar, are characterized by brittleness and limited ductility leading to low seismic resistance. These structures lack substantial deformation capacity before failure, making them susceptible to sudden and catastrophic collapse when exposed to seismic loading. Moreover, the age of the structures, combined with poor construction practices, lack of maintenance, and exposure to environmental degradation, increases their vulnerability. In many cases, the structural elements are not reinforced with steel or other materials, which limits their capacity to resist seismic forces. The use of non-ductile materials, such as unreinforced masonry, and the lack of proper connections between the structural elements, also contribute to the low seismic resistance. These structures are susceptible to seismic events, which can result in significant damage or even collapse. To better understand the seismic behaviour of historical masonry structures, researchers have conducted numerous studies and assessments (Sarhosis et al. 2021, 2022, Vlachakis et al. 2020).

The seismic performance of historical masonry structures is dependent on several factors, including the structure's geometry, size, masonry material quality, and the seismicity level of the region. Stiffness, damping, and strength of structural elements play crucial roles in influencing the seismic response of masonry structures. The structure's stiffness and damping impact the distribution of seismic forces, while strength determines its capacity to withstand these forces. Assessing the seismic behaviour of historical masonry structures poses a significant challenge due to the lack of reliable data on structural and material properties. Unlike modern structures adhering to strict seismic codes, historical constructions were often built using traditional methods without detailed engineering calculations, making accurate seismic behaviour estimation difficult. To address this challenge, various experimental and analytical techniques have been devised, including laboratory tests on material samples, in-situ testing of structural elements, and numerical modelling. These methods offer valuable insights into the structural behaviour of historical masonry structures and aid in formulating appropriate retrofit strategies to enhance their seismic resilience.

As part of the current investigation, the authors conducted on-site inspections of historical masonry structures in the earthquake-affected region that experienced damage in recent seismic events to evaluate their present structural condition. The visually assessed structures were classified into distinct categories such as regular buildings, mosques, church buildings, and masonry walls each thoroughly examined under these specific classifications. The outcomes of the inspection have been systematically presented to offer a comprehensive insight into the damage sustained by these significant historical structures located in Türkiye's East Anatolia Region. Figure 11 depicts the distribution of historical structures affected by the earthquake across the region, and Table 1 provides the corresponding names of these structures.

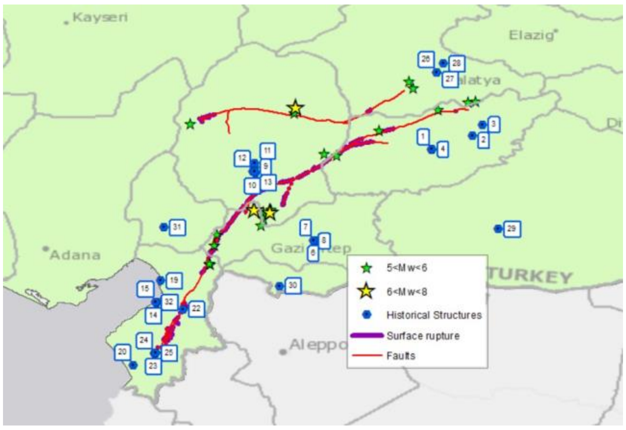


**Figure 11.** Location of the historical structures over the earthquake effected region.

**Table 1.** Corresponding structures.

| Historical Masonry Structures | | | | | |
|---|---|---|---|---|---|
| 1 | The Grand Mosque | 12 | Fatih Mosque | 23 | Antakya Greek Orthodox Church |
| 2 | Handshaking Columns* | 13 | Bayazıtlı Mosque | 24 | Antakya Protestant Church |
| 3 | Kahta Castle | 14 | St. Nicholas Orthodox Church* | 25 | Mahmeriye Mosque |
| 4 | Yenipınar Mosque | 15 | Iskenderun Catholic Church* | 26 | Yeni Mosque |
| 5 | Şirvani Mosque* | 16 | Hatay Council Building* | 27 | Hacı Yusuf Taş Mosque |
| 6 | Karagöz Mosque* | 17 | The Grand Mosque of Antakya | 28 | Sütlü Minaret |
| 7 | Kurtuluş Mosque* | 18 | Hatay Habib-I Neccar Mosque* | 29 | The Grand Mosque of Urfa |
| 8 | Bayazhan* | 19 | Sarı Selim Mosque, Payas* | 30 | The Grand Mosque of Kilis |
| 9 | The Grand Mosque of Kahramanmaraş (Mosque Kebir)* | 20 | Church of Mary, Samandağ* | 31 | Enverül Hamid Mosque |
| 10 | Arasa Mosque | 21 | Aziz Georgios Greek Orthodox Church | 32 | Mithatpaşa Primary School* |
| 11 | Saraçhane Mosque* | 22 | Darb-I Sak Castle | | |

∗Considered in this study.

### *4.1 Historical Masonary Buildings*

This section outlines the damage encountered by historical governmental and trading buildings, school structures, and the subsequent sections will detail the damage to mosques, churches, and masonry walls. Figure 12 shows the damage of the exterior walls of Bayazhan in Gaziantep. Bayazhan is a building characterized by a rectangular shape with an open section in the middle, and the building was constructed using the cut stone masonry. It was built in 1909 and underwent restoration in 2019 (Kultur Envanteri, 2023).

The distance of Bayazhan to the fault rupture line for the first earthquake is around 58 km. According to Figure 12b, the disintegration, mainly delamination of the external leaf, of masonry was observed during the site investigation conducted by the authors. In literature, this behaviour is also described as the "zero" mechanism, occurring when a masonry portion is incapable of resisting nearly any horizontal force and disintegrates into pieces (Indirli et al. 2013, Vlachakis et al. 2020). Figure 12c illustrates the overturning of gable end walls known as local failure mechanism which is due to the inadequate connection with the roofing system and the walls. Similar failure mechanism is also reported by Güleç (2023) in which the author observed failures due to inadequate connection between roof system and the walls.


**Figure 12.** Bayazhan in Gaziantep, (a) Bayazhan before Kahramanmaraş earthquakes (Photo Credit: Gaziantep Provincial Directorate of Culture and Tourism). (b) Damage at the walls of the east side of Bayazhan. (c) Damage at walls the west side of Bayazhan.

The mainshock's maximum Mercalli intensity (MMI) was estimated to have reached MMI XI–XII in Antakya and near the epicenter. MMI XI or higher was observed along the fault rupture from the epicenter to Antakya, spanning approximately 400 kilometers. The evident fault rupture and near-field effects led to severe building damage and collapses in Antakya during the Mw 7.7 earthquake. Additionally, Antakya is situated in the Amik basin, a Holocene sediment-filled basin bounded by two strands of the Dead Sea Fault System to the east and west. The values for peak ground acceleration (refer to Figure 6) and peak ground velocity are notably (Erdik et al., 2023) higher in the Hatay Province to the southwest, likely due to basin amplification effects and directivity effects. (Erdik et al. 2023, Kazaz et al. 2024, METU-EERC 2023). The Hatay Council Building, situated in Antakya Province (refer to Figure 13a), experienced severe structural damage during the earthquake. The construction of the building was completed in 1928, and the building consist of cut stone load-bearing walls and reinforced concrete column forming the core around the courtyard. As depicted in Figure 13b, the load-bearing system constructed with cut-stone completely collapsed, and the reinforced concrete columns failed, exhibiting weak column behaviour at the connections. Figure 13c and 13d depict Mithatpaşa Primary School, built in 1926 by the French, located in Iskenderun Province in Hatay. The school, constructed with rubble stone featuring long walls and a timber roof, experienced complete collapse of the roof and the second floor during the Kahramanmaraş earthquake sequence.

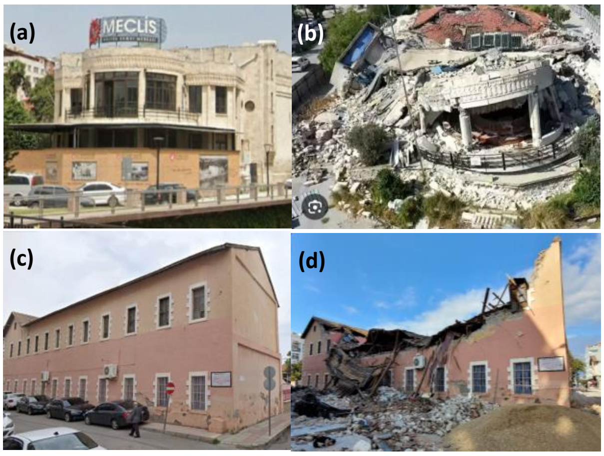


**Figure 13.** (a) Hatay Council Building before Kahramanmaraş earthquakes (Google Earth, 2022). (b) Hatay Council Building, damage after the earthquakes (CNN TURK, 2023). (c) Mithatpaşa Primary School, Kahramanmaraş earthquakes (Google Earth, 2022). (d) Mithatpaşa Primary School, damage after the earthquakes.

### *4.2 Historical Masonary Mosques*

Masonry mosques are commonly found in many parts of the world, and their seismic behaviour has been the subject of considerable research (Arıoğlu and Anadol 1973, Caktı et al. 2013, Doğangün et al.,2007, Kocaman and Kazaz 2023, Saygılı et al. 2023). These studies provide valuable insights into the seismic behaviour of masonry mosques and offer practical solutions for improving their seismic resistance. In Turkish architecture, particularly during the Anatolian Seljuk period, large mosques with masonry piers or wooden columns and multiple domes are referred to as 'ulu' mosque (the grand mosque). In the Ottoman period, mosques commissioned by sultans are generally called 'selatin' mosques (Tayla, 2007). The fundamental structural components of the mosque's supporting system include a main dome, buttresses, secondary domes, and main arch. Detailed information about significant failures observed in the structural elements of the mosques is provided in the following subsections.

Recent articles related to the 2023 earthquakes are also pointed out the damages observed in masonary mosques

(Avğın and Köse 2023, Onat et al. 2023, Kocaman et al. 2024, Işık et al. 2023).

Figures 14a and 14b represent the complete collapse of The Habibi Neccar Mosque, situated in Antakya Province, where high PGA values were documented (AFAD, 2023; Erdik et al., 2023). The Habibi Neccar Mosque, initially constructed around the 7th century and recognized as the first mosque in Anatolia, underwent reconstruction around the 11th century and has undergone multiple repairs over time (Hatay Governorship, 2024). The Habibi Neccar Mosque is a masonry structure that was constructed with cut stone. The collapse of the masonry dome was followed by the out-of-plane behaviour of the masonary walls. URM walls are most vulnerable to flexural out-of-plane behaviour (Oyguc and Oyguc, 2017). The partial collapse of the Grand Mosque of Kahramanmaraş is depicted in Figures 14c and 14d, with the partial collapse of its minaret. The Grand Mosque of Kahramanmaraş was built in 15th century and belongs to the group of mosques with wooden ceilings. The mosque, reflecting the characteristics of the early Anatolian Seljuk architecture and the exterior walls are constructed of rough-cut and rubble stone.

### *4.2.1 Minarets*

Masonry minarets are tall, slender structures that have been used for centuries as architectural features of mosques and other religious buildings. In Anatolia, the earliest minarets were built by the Seljuks. Usually, the minarets had a stone base and a brick shaft. The transition from the square base to the circular form of the shaft was realized by means of Turkish triangles (Uluengin et al., 2019). Figure 15 shows the sections of a typical minaret: (1) spire, (2) upper part of the minaret body, (3) balcony, (4) cylindrical or polygonal body/shaft (5), transition segment, (6) pulpit.

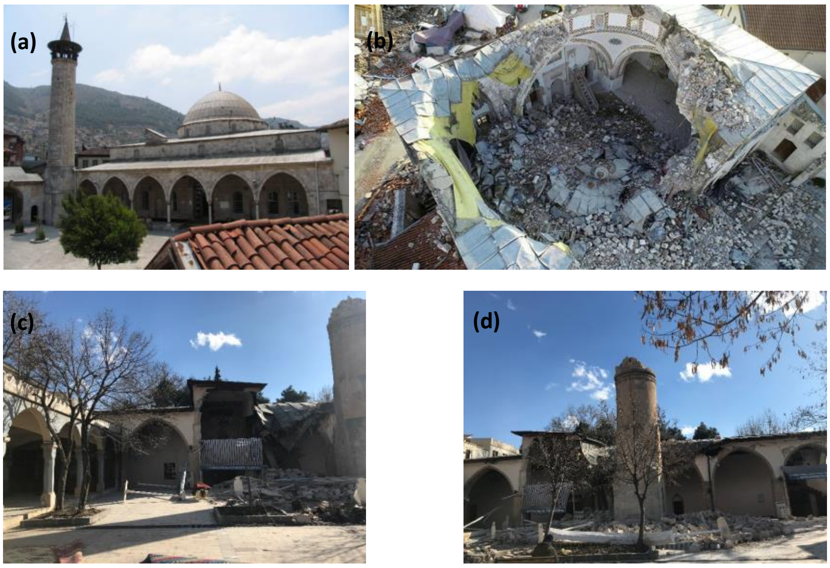


**Figure 14.** (a) Habib-I Neccar Mosque before the Kahramanmaras Earthquakes (Google Earth, 2022). (b) Damage in Habib-I Neccar Mosque the after the earthquakes (DHA, 2023). (c) Damage in The Grand Mosque of Kahramanmaraş after the earthquakes, (d) Damage in The Grand Mosque of Kahramanmaraş after the earthquakes.

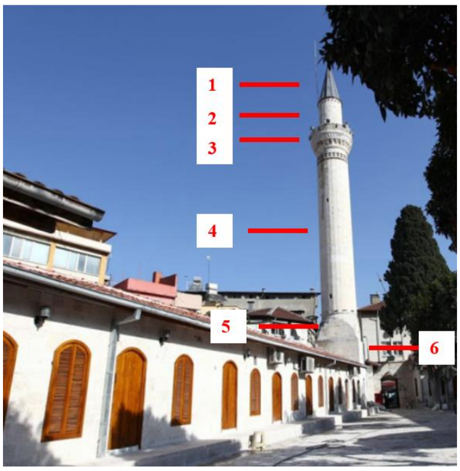


**Figure 15.** The Grand Mosque of Antakya before the Kahramanmaras Earthquakes and details of a typical minaret (Antakya Municipality, 2015).

Due to their height and slender nature, these structures are vulnerable to seismic forces, which can cause them to sway and potentially collapse.

As part of the current investigation into the evaluation of historic masonry structures in the earthquake-affected region following recent seismic events, the authors visually inspected several minarets to assess their current structural condition. In particular, the differences between the pre-earthquake and post-earthquake states of these structures were investigated to better understand the extent of the damage sustained by the earthquakes. For this purpose, the image of the minarets was obtained following the earthquakes, facilitating a thorough visual analysis of the structures. These photographs offer a detailed illustration of the damage incurred by the minarets, showcasing the diverse structural alterations resulting from the seismic events. By presenting these images, the objective is to offer a more holistic insight into the effects of earthquakes on historic masonry structures, particularly minarets. Through this presentation, the aim is to contribute to the advancement of more effective measures for earthquake-resistant design and construction practices in the future. As an example, Figure 16a shows the minaret of Sarı Selim Mosque in Iskenderun, constructed in the 16th century, while Figure 16b illustrates the minaret of Karagöz Mosque in Gaziantep, built in the 18th century, both constructed using masonry techniques. According to both figures, damage is evident in the balcony section of the minarets. As reported by Doğangün et al. (2007), minarets are more susceptible to damage in areas such as the hood, upper part, balcony, and transition sections during seismic events. The region above the balcony experiences maximum displacement, and the lack of stairs in the upper body contributes to reduced rigidity, leading to a rapid increase in the displacement. Figure 16c and 16d shows the Şirvani Mosque in Gaziantep constructed in 17th century as masonry structure. The collapse of the minaret lead to extensive damage also at the mosque.


**Figure 16.** (a) Damage in the minarets at Sarı Selim Mosque in Iskenderun, Hatay. (b) Damage in Karagöz Mosque in Gaziantep city centre. (c) Şirvani Mosque in Gaziantep before the Kahramanmaraş Earthquakes (Google Earth, 2022). (d) Collapse of the Minaret of Şirvani Mosque after the earthquakes.

#### *4.2.2 Domes*

Masonry domes, often found in historical structures, are distinguished by their curved and spherical design, playing a crucial role in covering large interior spaces in temples, palaces, churches, and mosques. These domes, being constructed with materials that possess minimal tensile strength, are susceptible to significant damage and collapse when subjected to powerful seismic forces. Instances of severe structural damage and collapses in masonry domes have been documented in historical events (Bayraktar et al., 2022). Domes serve as structural elements covering surfaces of buildings with square, polygonal, and circular floor plans in three-dimensional space. These curved surfaces bear vertical forces, including their own weight and external loads like snow. In historical constructions, masonry is commonly employed as the primary material. The structural concept relies on the distribution of loads from the uppermost keystone to adjacent stones, gradually transferring the load to the dome's base (Bilgin, 2006).

Figure 17a and 17b illustrates the Gaziantep Kurtuluş Mosque prior and after the Kahramanmaraş earthquake sequences. The Gaziantep Kurtuluş Mosque, formerly known as the Virgin Mary Church, is a 125-year-old structure constructed with cut stone. Originally built as a church in 1892, this historic building, situated in Gaziantep, served as a prison after its church function until 1980. Subsequently, it underwent conversion into a mosque (Güllü and Karabekmez, 2016). The central dome, spanning approximately 12 meters in diameter, has a height of 30 meters above the ground (Güllü and Karabekmez, 2016). The collapse of the dome occurred in the mosque, which is mainly due to significant diameter of the dome and due to the insufficient connection to the body of the main structure. The typical damage at the balcony of the minaret also occurred in the mosque.

(a) (b)

**Figure 17.** Kurtuluş Mosque in Gaziantep before the Kahramanmaraş Earthquakes (Google Earth, 2022). (b) Dome and minaret damage in Kurtulus Mosque after the earthquake.

### *4.3 Historical Masonary Churches*

Churches are the significant historical structures of the region with their architectural features. Out-of-plane failure mechanism were observed in the churches. In the absence of a 'box like behaviour' of structures, the internal forces of the walls perpendicular to the seismic action give rise to out-of-plane bending. Long walls or walls with insufficient transversal support suffers vertical, one-way bending as seen in Figure 18 in Iskenderun Catholic Church. The walls experienced out-of-plane failure, also due to the top part of the façades might inadequately connected with the roof, and the wall behaves as a cantilever about their base (rocking type of failure) (Vlachakis et al., 2020).

(a) (b)

**Figure 18.** Iskenderun Catholic Church (a, b) Out-of-plane damage in the Iskenderun Catholic Church after the earthquake.

Multiple failure mechanisms observed during the field studies in St. Nicholas Orthodox Church in Iskenderun, Hatay (see Figure 19). The distance of the church to fault rupture is around 18 kilometres. The church's construction was initiated in the 1870s and features masonry construction, with load-bearing walls composed of brick or stone. The church experienced damage during the Amik earthquake of 1872 and reopened after 1876. Out-of-plane mechanism of the front wall at the entrance of the Church were examined as reported in Figure 19a and 19b.

(a) (b)

**Figure 19.** St. Nicholas Orthodox Church in Iskenderun, (a, b) Observed combined in-plane and out-of-plane mechanisms in the St. Nicholas Orthodox Church after the earthquake.

In addition to out of plane mechanisms, in-plane damages were also observed. As reported by Güleç (2023), cracks commonly form around openings such as doors and windows due to stress concentrations. Based on the observations of Güleç (2023) and the guidelines outlined in the Turkish Building Earthquake Code (TBEC,2018) intersecting walls or vertical tie beams (e.g., timber) can be employed to mitigate these cracks. According to the TBEC, the spacing between vertical tie beams in newly constructed unreinforced masonry structures must not exceed four meters. Therefore, during the restoration process, careful attention should be given to maintaining this spacing.

## 6. Conclusions

On February 6th, 2023, a powerful earthquake struck the province of Kahramanmaraş in Türkiye. The earthquake had a magnitude of 7.7 on the Richter scale, and it was followed by another strong earthquake with a magnitude of 7.6. The earthquakes caused significant loss of life and injury, and significant disruption to the region's historical masonry structures. Seismic behaviour of historical masonry structures is a significant concern for the preservation of the worlds' cultural heritage and the safety of people. These structures are vulnerable to seismic loading due to their low strength, poor seismic detailing, and limited ductility. This vulnerability resulted in cracking, displacement, and even collapse under the force of ground motion. In addition to its inherent weakness, the damage to masonry mosques can be worsened by a range of factors, including inadequate reinforcement and detailing, poor construction quality, and insufficient maintenance. The combination of these factors led to partial or total collapse of the structures.

On-site observations indicate that historical buildings are susceptible to various types of damage and malfunctions that can be classified into several categories. For example, cracks and slight shifts in the stones of the minarets were observed, as well as failures above the balcony area. Minor cracks in the vertical connections of mosque walls were also observed, which can be remedied with paint. In addition, failure in church buildings due to use of long walls, and lack of quoin stones in the corners were observed.

To ensure the historical masonary structures' resilience to seismic events, it is essential to assess their seismic behaviour accurately and develop suitable assessment, restoration and retrofit strategies. The seismic performance of masonry structures can be enhanced by utilizing high-tensile-strength fiber-reinforced mortar or steel reinforcement systems, all while preserving the historical significance of the structures. Adhering to seismic design codes is crucial throughout the reconstruction process (e.g., material properties, unreinforced length of the walls). The preservation of our cultural heritage is a collective responsibility, and ensuring the seismic resilience of historical masonry structures is an essential part of it. The current study presents a clear before-and-after comparison, to demonstrate the urgent need for effective seismic safety measures in the design, construction, and maintenance of historical masonry buildings. Furthermore, learning from past earthquakes and applying this knowledge to reduce future vulnerabilities will strengthen community resilience and decrease the likelihood of disasters.

**Declaration of Ethical Standards**

*It is hereby declared that scientific and ethical principles were followed during the preparation of this work, and all sources used are cited in the reference list.*

**Credit Authorship Contribution Statement**

Author-1: Conceptualization, investigation, visualization and writing – original draft.
Author-2: Conceptualization, writing – review and editing.

**Declaration of Competing Interest**

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

**Data Availability Statement**

The authors declare that the main data supporting the findings of this work are available within the article.

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