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A systematic method for post-earthquake damage assessment: Case study of the Antep Castle, Türkiye

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Abstract

Although there is no definite information about when and by whom Antep Castle was built, its history dates back 6000 years. The walls of the Antep castle were built in the Byzantine Period in the 6th century AD, and it is the most important structure of Gaziantep with its historical monument value and its significant contribution to the National Struggle in history. The castle was used during the occupation of Antep, and today it has the Heroism and Panorama Museum, which tells about the events that took place during the national struggle. In the earthquakes that took place on February 6, 2023, with an interval of 9 hours, the massive damage to the Antep Castle and its walls caused the castle to become the symbol of the earthquake in Turkey. In order to ensure the sustainability of our cultural heritage, there is a need for a detailed and systematic assessment of the damage assessment of Antep Castle and walls after the earthquake. The main purpose of this study is to discuss the damage observed after the earthquake in the historical Antep Castle and its walls in Gaziantep, Turkey. In the study, literature research, on-site visual examination and tabulation methods were applied. Based on the problems seen in the post-earthquake fortifications in different countries in the world, a table of damage mechanisms was created that can be used as a tool to classify post-earthquake damages on the walls on a geographical basis. The method presented in this study will save a great deal of time, money and effort in the evaluation and rehabilitation of fortifications with cultural and strategic historical importance.

1. Introduction

The Gaziantep-Kahramanmaraş earthquakes took place on February 6, 2023, with an interval of 9 hours, with a magnitude of Mw 7.7 and Mw 7.6, with epicenters in Pazarcık (Kahramanmaraş) and Elbistan (Kahramanmaraş) [1]. After these earthquakes, at least 12,141 buildings were destroyed in Turkey. Many historical buildings, including Gaziantep Castle, Şirvan Mosque, Yeni Mosque in Malatya and the Latin Catholic Church in İskenderun, were heavily damaged and partially destroyed. In the statement of the General Directorate of Cultural Heritage and Museums of the Ministry of Culture and Tourism regarding our 'Museums and World Heritage Sites in the Provinces Affected by the Earthquake', it is stated that Antep Castle and its Walls are one of our historical buildings damaged in the earthquake [2]. Antep castle and walls were built in the Byzantine Period in the 6th century AD, and it is the most important structure of Gaziantep with its historical monument value, magnificence, majesty and significant contribution to the National Struggle in history. The castle was used during the occupation of Antep, and today it has the Heroism and Panorama Museum, which tells about the events that took place during the national struggle. Gaziantep Castle, which managed to stand upright by defying the centuries, caused great damage in the earthquakes that took place on February 6, 2023, with an interval of 9 hours. The extent of the damage caused the castle to become a symbol of the earthquake in Turkey. In order to ensure the sustainability of our cultural heritage, there is a need for a detailed and systematic assessment of the damage assessment of Antep Castle and walls after the earthquake. In this respect, in order to ensure the sustainability of the historical heritage, there is a need for a detailed and systematic assessment of the damage assessment of Antep Castle and its walls after the earthquake.

A limited number of studies have been conducted on the seismic damage to which the castle walls are exposed [3-8]. In some of these studies, damage classification was made as the basis for a proposal for a table cataloging the main damage mechanisms identified in forts hit by earthquakes [9,10]. In the results of these studies, it is stated that these tables are defined by considering only a limited number, and in order to catalog the damages caused by earthquakes in the fortification structures in the future and to determine the preventive protection, tables that catalog the main damage mechanisms in the post-earthquake fortresses should be developed in each region on a geographical basis. It is expressed that it is necessary to carry out studies that include more cases from different areas by indirectly considering earthquake characteristics, building typologies, materials.

Based on the recommendations and requirements presented in the results of the studies in the literature [9,10], this study discusses the post-earthquake damage to the Antep castle and its walls in Gaziantep, Turkey. As a method in the study, on-site visual inspection and tabulation methods were applied. In this context, a table was created that catalogs the post-earthquake damages on the walls on a geographical basis. The application of the damage table created in different regions will allow the different behavior of the fortification structures in different geographical regions to be compared in the earthquake. In addition, these guidelines will allow the identification of a priority list according to damage mechanisms, ensuring that responses are focused on the most sensitive elements. Thus, it is hoped that it will be possible to strengthen a larger number of fortification structures within a certain budget. Most of the fortifications of high cultural and historical importance in the world were built using masonry. Considering this situation, it is thought that such a method will save a very high level of time, money and labor for the evaluation and rehabilitation of existing wall masonry structures. The first step to preventive response in historic walls is to identify recurring vulnerabilities. The results of the study will allow the comparison of damage in fortification structures with different characteristics in terms of materials, building typologies and protection status.

2. Study Area

Gaziantep province is one of the important cities in Turkey's Southeastern Anatolia Region in terms of historical, touristic, industrial, commercial and educational aspects. It is built on a plateau from which it takes its name and is located between the intersection of the neighboring Syrian Plateaus. Gaziantep is border neighbor to Kilis in the south of the region, Adıyaman and Kahramanmaraş in the north, Şanlıurfa in the east, Adana and Osmaniye in the west. It is a city located between 36° 28' and 38° 01' east longitude, 36° 38' and 37° 32' north latitudes and where population mobility is experienced significantly. According to 2022 TUIK data, the population of Gaziantep was determined as 2,154,051 [11].

This location of the city of Gaziantep is seen to be at an important key point in the region both today and in the historical process. This location of the city has been an important settlement center and bridge for many civilizations together with Mesopotamia, where the first civilizations of history were formed. Gaziantep's location on the historical Silk Road, which connects the Middle East and the Far East, as well as the border extending to the Mediterranean, has caused the city to maintain its importance until the ancient civilizations due to its historical function in the region called Commagene, which connects the regions and borders of the city. Being located on the historical Silk Road line, the transit route of historical commercial caravans, is the most important factor that makes Gaziantep one of the most developed and most important industrial cities with a significantly rich commercial volume in Turkey today [11].

Although it is not known exactly when and by whom the castle was built, its history dates back to 6000 years ago. It has been understood by archaeological excavations that the castle was first built as a watchtower in the Roman period and expanded over time. It took its current form during the reign of Byzantine Emperor Justinian, known as the architect of castles. During this period, the castle underwent an important repair. In the years after the Byzantine period, the Mamluks, Dulkadiroğulları and Ottomans repaired the castle from time to time. It is understood from the inscription on the main gate that the towers on both sides of the main gate and the castle bridge were rebuilt by Suleiman the Magnificent in 1557 [12].

The castle has been restored many times throughout history and took its final form with a restoration in the early 2000s. The castle underwent an important repair in the 527-565 AD, and the southern section was equipped with substructure (foundation) structures consisting of arched and vaulted galleries in order to provide leveling during the repair. Towers connected by these galleries were built and the walls were extended to the west, south and east, up to the border of the hill. In this state, the castle has an irregular circular shape with a diameter of about 100 m and a circumference of 1200 m. There are 12 towers on the castle bodies. Evliya Çelebi mentions the 36 constellations of the Castle in his Travelogue. Today, we can only see 12 of them. It is thought that the remaining 24 bastions were located on the outer walls of the castle and did not survive until today.

The castle was built in a circular plan and the perimeter of the castle is 1200 m long. The walls built of large stones obtained from lime rocks in the geological structure of the region were supported by 12 towers and bastions. At the first entrance from the castle gate, there are two roads leading to the inner parts and the upper part. While reaching the upper part of the castle with the left road, the other road leads to the galleries, corridors and other castle rooms [13].

Figure 1. Gaziantep Castle before the 2023 Gaziantep-Kahramanmaraş earthquakes

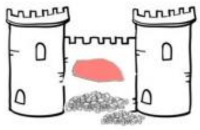
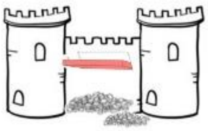
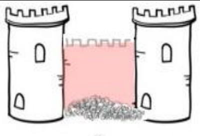
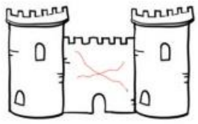
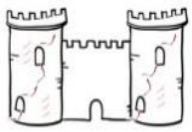
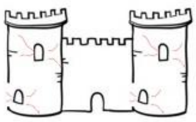
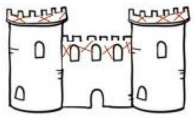
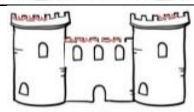
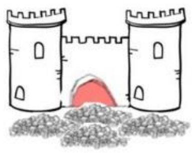
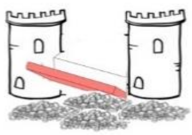
3. Material and Method

In the first stage of the study, the damages that occurred after the earthquake in the historical city walls in different parts of the world were investigated by literature review. In the second stage, a damage table was created to categorize the damages in the fortification structures on a regional basis. In the study, the table of damage mechanisms proposed by Coïsson et al. [10] is arranged in some specific mechanisms, with some changes made on a geographical basis for Turkey. Within the scope of the study, the damage mechanism table created on a geographical basis was used as a tool for the post-earthquake damage assessment of the Antep castle and its walls.

Damages on the walls are categorized according to the building elements in the table created. The structural elements specified in the table and the types of damage coded by classification are explained in Table 1.

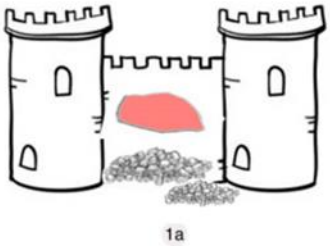
- There are two types of damage seen in masonry elements: Crumbling of masonry (1a) and delamination of the cladding (1b)
- There are three types of damage seen in walls elements: Cracks caused by the different dynamic behavior between tower and wall (2a), in plane shear cracks (2b) and out of plane overturning (2c)
- There are two types of damage seen in main body of the tower elements: Shear cracks in the main body of the tower (3a), with possible torsional effects if the tower is asymmetrically connected to the walls, shear cracks in the upper part of the tower (3b)
- There are two types of damage seen in merlons elements: In plane flexural or shear cracks (4a); overturning (4b)
- There are two types of damage seen in foundations elements: Fall of the foundation rock or settlements of the soil (5a); Overturning of walls caused by the dynamic thrust of the earth (5b)

Table 1. Identification and classification of damage mechanisms (Modified from Coïsson ve diğerleri [10])

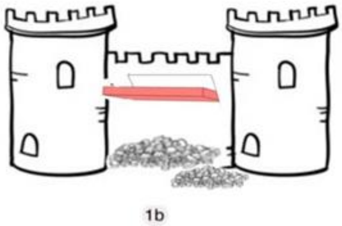
Code	Definition	Schema	Construction elements				
			Masonry	***Walls***	***Main body of the tower***	***Merlons***	***Foundations***
(1a)	• Crumbling of masonry		✖				
(1b)	• Delamination of the cladding		✖				
(2a)	• Cracks caused by the different dynamic behaviour between tower and wall			✖			
(2b)	• In plane shear cracks			✖			
(2c)	• Out of plane overturning			✖			
(3a)	• Shear cracks in the main body of the tower				✖		
(3b)	• With possible torsional effects if the tower is asymmetrically connected to the walls, shear cracks in the upper part of the tower				✖		
(4a)	• İn plane flexural or shear cracks					✖	
(4b)	• Overturning					✖	
(5a)	• Fall of the foundation rock or settlements of the soil						✖
(5b)	• Overturning of walls caused by the dynamic thrust of the earth						✖

4. Results

The damages that occurred in the Antep castle and its walls were classified according to the building elements (Table 1). Damages on masonry is shown in (Figure 2), walls (Figure 3), main body of the tower elements (Figure 4), merlons (Figure 5) and foundations (Figure 6).



crumbling of masonry (1a)

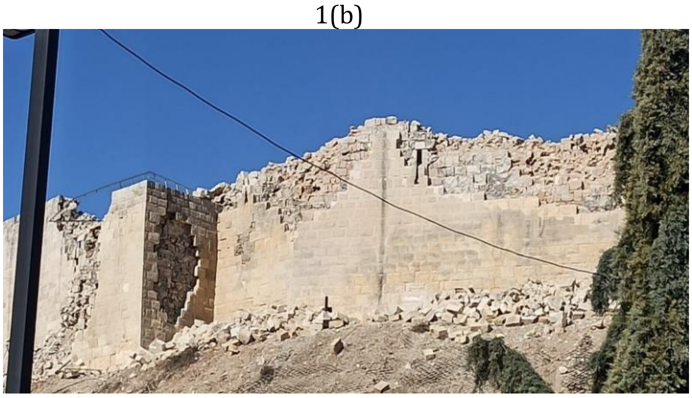


delamination of the cladding (1b)

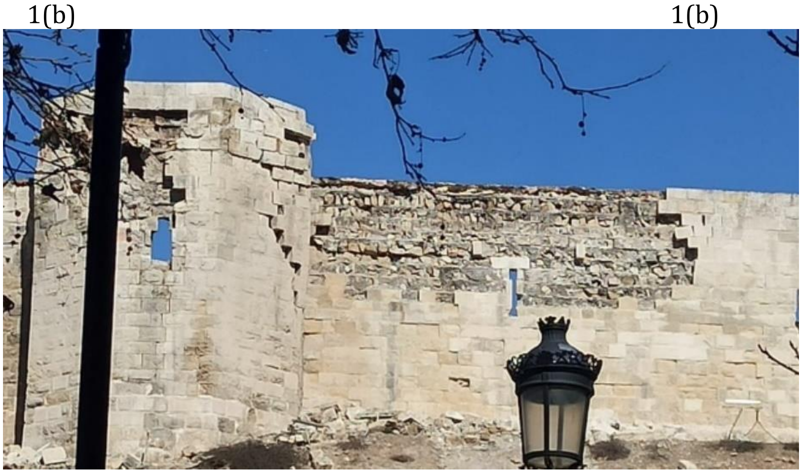
1(a)

1(b)

1(b)

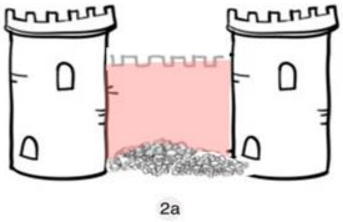


1(b)

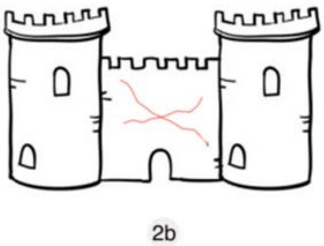


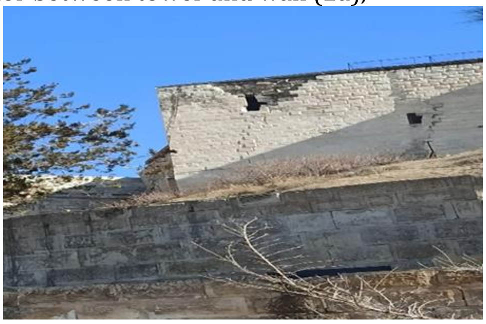
1(b)

Figure 2. Types of (1a) and (1b) damage in the castle

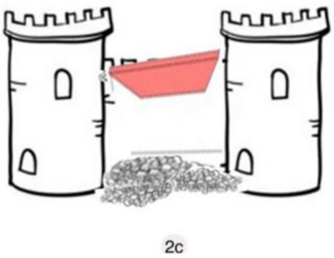


cracks caused by the different dynamic behavior between tower and wall (2a),



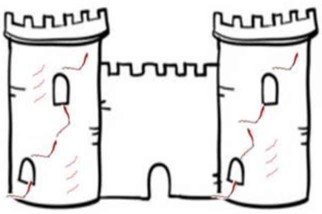


plane shear cracks (2b)

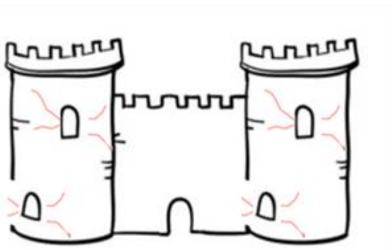


out of plane overturning (2c)

Figure 3. Types of damage (2a), (2b) and (2c) on the walls of the castle

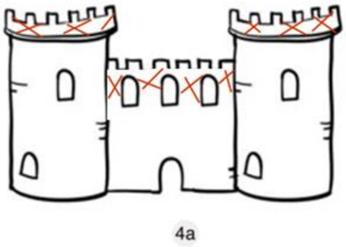



shear cracks in the main body of the tower (3a)

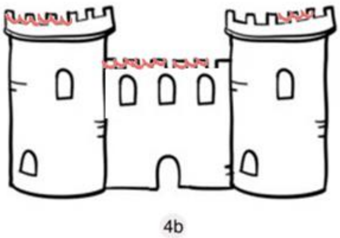



with possible torsional effects if the tower is asymmetrically connected to the walls, shear cracks in the upper part of the tower (3b)

Figure 4. Types of (3a) and (3b) damage seen in the castle

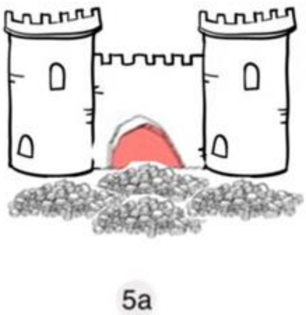


flexural or shear cracks (4a)

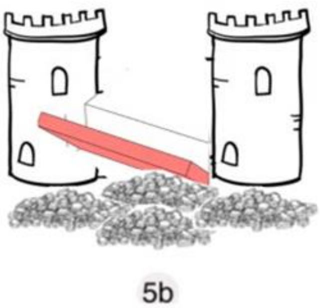


overturning (4b)

Figure 5. Types of (4a) and (4b) damage seen in the castle



fall of the foundation rock or settlements of the soil (5a)



overturning of walls caused by the dynamic thrust of the earth (5b)

Figure 6. Damages (5a) and (5b) seen in the castle

5. Discussion

The main purpose of this study is to discuss the damage observed after the earthquake in the historical city wall located in Gaziantep Province of Turkey. The problems identified by on-site visual inspection in the study are presented in the table created by considering the geographical region within the scope of the study. The results of the study show that using the classification proposed in the study to catalog and analyze damage to fortification structures is an effective tool for applying an empirical approach to the seismic behavior of cultural heritage.

The damage mechanisms table used in the study to determine damage is the version of the verified version on more than 70 damaged castles characterized by different materials and construction techniques [5] based on the geography of Turkey. Considering the results of the study, the table of damage mechanisms applied on the Antep castle, which is organized on a geographical basis within the scope of the study, seems to expand its validity in Turkey. The results obtained from the study show the relationship between the characteristics of the fortification structure and the specificity of each area considered in terms of exposed damage, which are numerical studies published in several specific literature [9,10].

As a result of the observational analyzes on the damage typologies according to the characteristics of the building, it was determined that the most common damage after the earthquake in the 6000-year-old castle was caused by the shearing of the cut stones used on the front surfaces of the castle walls. The reason for such damages is the reactions of different types of materials used in the fortification walls against horizontal loads. Antep fortification walls are double paries walls. While the use of cut stone is seen on the front faces, the middle parts are filled with rubble stone. Since the responses of cut stone and rubble stone to horizontal loads during an earthquake are different, it is frequently seen that the cut stones on the front faces of the walls are separated from the rubble stones and poured. In particular, the type of masonry, which is closely linked to the local resources available in the region, seems to strongly influence the damage mechanisms. This finding supports the conclusion that Coisson et al. [14] determined that the construction technique is related to the crumbling and delamination of the wall.

In addition, merlons were damaged in the building elements, and frequent cutting damages were detected on the walls. The cracks in the main walls of the castle and widespread damages on the upper parts of the merlons were directed by the partial collapse of the upper part of the walls. When we examine the destruction mechanisms, we see that the fortification walls generally spill from the upper parts and experience separation problems. Also, it is possible to notice that the building, which was completely destroyed due to the collapse of the walls, is in a dilapidated condition. In addition, the damages that occur frequently on the floor are described in general terms and it is not clear whether this is due to the rotation or deterioration of the walls. However, data collected on this seismic event is still limited and more research is needed.

In this context, the damage caused by the earthquake must be repaired urgently to prevent further damage and possible threat to the global strength and stability of the building [15-18]. Non-destructive methods such as laser scanning and UAV are very useful for damage detection in cultural heritage studies of gigantic structures such as fortifications [19-23]. In the future, it is planned to model the damage problems of the structure using terrestrial laser scanning. With terrestrial laser technology, damages in huge masonry structures can be detected with high precision [24-28].

6. Conclusion

This study includes the first reports of the damage to the city walls from the 2023 Gaziantep-Kahramanmaraş earthquake. In summary in the results of the study, it is seen that the observed damages are mostly due to the insufficient resistance caused by the use of different building materials together. The analyzes provide a valuable picture of active damage mechanisms, providing useful clues for reconstruction. In addition, the visual analysis results show that the limited upgrading of the mechanical properties of the walls in the destroyed parts of the castle can significantly limit the seismic fragility of the structure in light of the reconstruction. When the behavior of the building in earthquake is evaluated, it is clear that reinforcement should be done to increase the seismic resistance level of the building.

The results obtained in this study are important as they allow the determination of the characteristics of the historical Antep fortress and the city walls and which elements may be exposed to a higher risk in relation to earthquakes. The results of our study will provide useful indicators for interventions aimed at preserving our cultural identity. In future research, experimental studies should be carried out to consider the material to be used for repair, especially for the selection of materials that can significantly limit the seismic fragility of the structure by increasing the mechanical properties of the damage in a limited way.

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Author contributions

Lale Karataş: Conceptualization, Methodology, Software, Visualization, Investigation, Writing-Reviewing; **Tahir Ateş:** Writing, reviewing; **Aydın Alptekin:** Editing, Writing-Reviewing; **Murat Dal:** Reviewing; **Murat Yakar:** Reviewing

Conflicts of interest

The authors declare no conflicts of interest.

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