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INVESTIGATION OF CORNER FAILURE MECHANISMS OF MASONRY STRUCTURES CAUSED BY THE 6 FEBRUARY 2023 KAHRAMANMARAS EARTHQUAKES IN MALATYA

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Abstract. Corner failure mechanisms observed in masonry structures generally result in severe cases such as large amount of material damage, out of use or loss of life. Despite these negative effects, there has been limited research on the corner failure mechanism and the number of studies based on observations after the earthquake is much less. Within this study, first of all, literature information about the corner failure mechanism is presented and brief information is given about how numerical and experimental studies are carried out to investigate this failure mechanism. Afterwards, corner failure mechanisms in masonry structures in Malatya after the earthquakes in Kahramanmaraş on February 6, 2023, were investigated. In the examinations, it was determined that the corner collapse mechanism was caused by insufficient wall-roof connection, insufficient wall-slab connection, insufficient axial load, insufficient material strength, poor workmanship, and lack of engineering service. In addition, the corner failure mechanism has been observed as out-of-plane failure in many structures which is the most observed and known failure type in masonry structures, and it has been determined that the corner failure mechanism is triggered by out-of-plane and in-plane failure.

Keywords: masonry structures, corner failure, earthquake, Kahramanmarash earthquake

Introduction. It is thought that the masonry wall can theoretically have two classes of failure modes, in-plane and out-of-plane, without impairment between brick and mortar. [1-2]. Out-of-plane behaviour includes overturning mechanisms as shown in Figure 1, as well as belt-effect mechanisms classified as horizontal and vertical bending mechanisms. In-plane mechanisms, on the other hand, are the mechanisms in which each wall works individually and consists of various crack patterns such as crushing, tension, bending, diagonal shear and shear cracks, as seen in Fig.2.

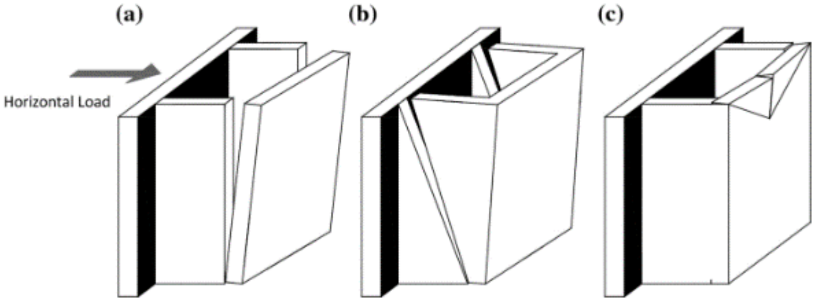


Figure 1. Out of plane mechanisms [2]

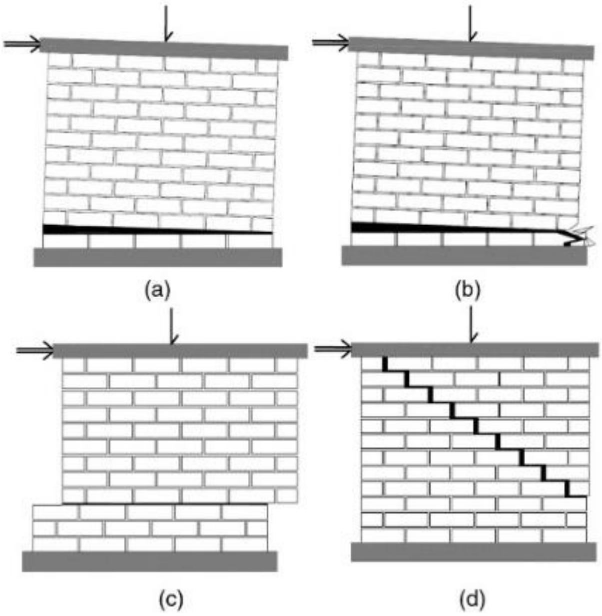


Figure 2. In plane mechanisms [2]

There are many experimental studies in the literature modelling the in-plane and out-of-plane behaviour of masonry structures under the influence of earthquakes [3- 7]. Apart from these failure mechanisms, the corner failure mechanism is the most important failure mechanism that will occur when a masonry structure is not constrained by other adjacent structures Although this failure mechanism is frequently observed under the influence of earthquakes, there are only a few studies [8-10] in the literature. Casapulla et al. (2018) [11] conducted an analytical study and updated the macro model approach to include frictional resistances. The most fundamental experimental study in the literature was conducted by Casapulla and Maione in 2020 [12]. Although there is an analytical section in the study, it is the first study to experimentally examine the corner failure mechanism. In this study, the experimental behaviour of a wall corner is analysed by simulating seismic horizontal movements through the gradual tilting of its base as shown in Figure 3. The corner wall joint is held at both free ends by a wooden system to simulate the connection effect associated with a larger extension of the real walls.

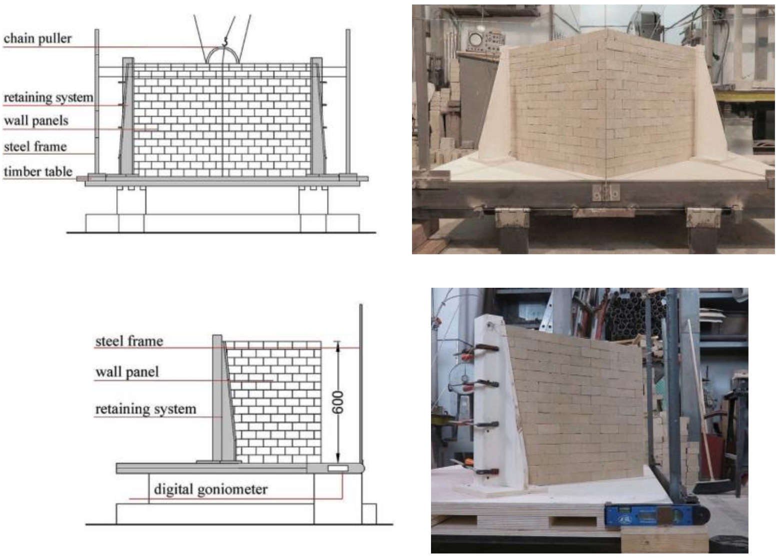


Figure 3. Experiment setup created by Casapulla and Maione (2020) [12]

When the studies presented so far are examined, and as a result of the observations made on site due to the earthquakes that occur frequently in our country, it is understood that masonry structures are frequently exposed to corner failure mechanisms under the influence of earthquakes. Photographs of a study made after the Sivrice (Elazıg) earthquake on February 9, 2007 are shown in Figure 4. As can be easily seen from the photographs, corner collapse mechanisms are present in the masonry structures in the region.

In another study examining the 2003 Bingöl Earthquake, In another study examining the 2003 Bingöl Earthquake [13] it was determined that the rate of collapsed heavily damaged masonry buildings in towns and villages was approximately 30%, and that there were major damages in buildings with loose corner connections. In the same study, it was observed that corner toughness could not be created in collapsed buildings, and houses with large stones in the corners were less damaged. Failure to make wall-to-wall and wall-to-slab connections in accordance with the procedures reduces the strength of the corners under the influence of earthquakes, and in particular, corner points that are not properly supported cause unstable [13]. Separation and corner damage at the corner points due to horizontal offset have been observed in many earthquakes and the importance of making a solid, rigid corner connection has been emphasized in other studies. [15]. Erkut Sayın and others [16]., who examined the Elazig earthquake, which our country has experienced recently and in which many lives were lost, saw and reported that weak wall-to-wall connections and the absence of vertical and horizontal beams in masonry structures caused structural corner breaks.

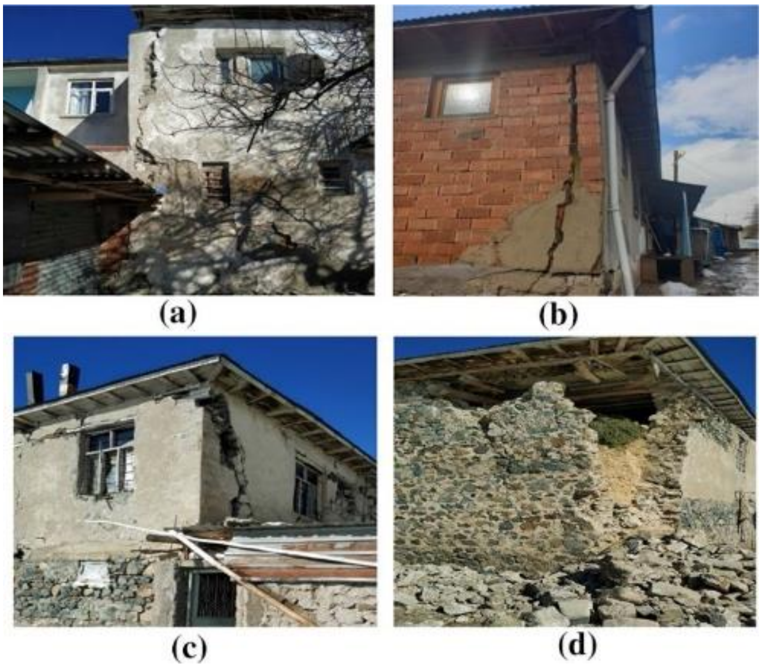


Figure 4. Corner failure mechanisms in masonry structures in the town of Sivrice [16]

Within this study, information about the earthquakes that took place in Kahramanmarash on February 6, 2023 was presented and then the corner failure mechanisms that occurred in the masonry structures in Malatya were examined.

6 FEBRUARY 2023 KAHRAMANMARASH EARTQUAKES. All of the information given in this section has been obtained from the website of the Republic of Turkey Ministry of Internal Affairs, Disaster and Emergency Management Presidency (AFAD).

The Eastern Anatolian Fault System (EAFS) forms a NE-SW left lateral strike-slip transform boundary with an average width of 30 km and a length of 580 km between the northward moving Arabian Plate and the westward moving Anatolian Block. [17-24]. It meets the westward movement of the Anatolian block together with the EAFS and the North Anatolian Fault System (NAFS), which is one of the most active and active fault systems in Turkey and forms the border between the Anatolian and Arabian Plates. EAFS starts from Karlıova junction point (Kargapazarı) in the northeast and extends as a single zone to the west of Çelikhan. The southern branch of the fault, which splits into two branches here, continues from the north of Gölbaşı Basin and Pazarcık to the Türkoğlu junction in the southwest. The fault jumping to the right in the south of Türkoğlu continues by limiting the Sağlık, Kocagöl and Amik plains from the west and ends by scattering in the south of Kırıkhan. In this part of the EAFS, the Sakçagöz and Narlı parts of the Dead Sea Fault Zone delimit the dent basin, which includes the Sağlık and Narlı plains, from the east. The Narlı part extends from the North of Pazarcık to the

EAFS for 30-40 km in the NNE direction. The northern branch, which separates to the west of Çelikhan, conforms to the morphology of the Southeast Taurus Mountain Belt and forms a convex bend to the north. This branch consists of the Sürgü Fault, Çardak Fault and the Savrun, Çokak and Toprakkale faults turning SW from Göksun (Figure 5).

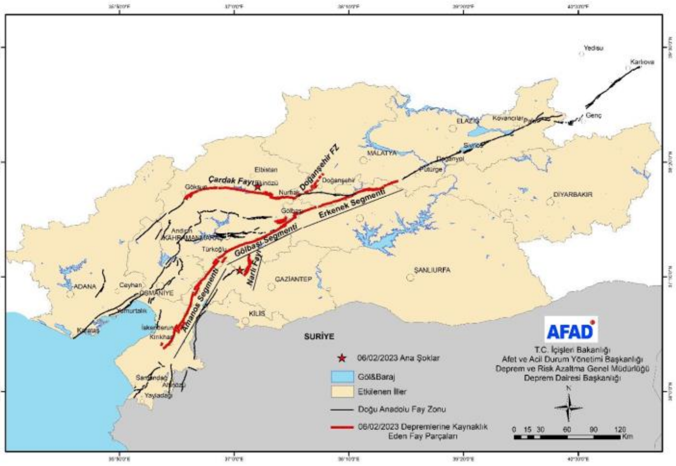


Figure 5. Map showing the fault parts of the Eastern Anatolian Fault System

The Eastern Anatolian Fault System, which was the source of many major earthquakes in the historical period until the early 1900s, had a seismically active period especially in the 19th century. It created a series of earthquakes that started with the 1789 Palu earthquake, continued with the 1822, 1866, 1872, 1874, 1875, and 1893 earthquakes, and finally ended with the 1905 Malatya earthquake at the beginning of the last century. Although it seems to have entered a relatively quiet period after this earthquake, the 22 May 1971 Bingol (Ms=6.8) 5 May 1986 (Ms=5.8) and 6 May 1986 (Ms=5.6) Doğanşehir earthquakes are earthquakes by EAFS. These earthquakes are the average earthquakes produced by this fault in the last century.

A total of 13 earthquakes (Ms > 5.0) occurred that damaged the EAFS even in this period, when EAFS, which did not produce more than 7 earthquakes in the 20th century and almost forgot itself, was calmer in terms of producing large earthquakes compared to the 19th century. However, none of these were greater than Ms=6.8. The epicentral distributions of these earthquakes tend to concentrate at the boundaries of the segments.

On EAFS, which entered a more active period in the 2000s, respectively; 01.05.2003 Bingol (Mw 6.3), 14.03.2005 Karlıova Bingöl (Mw 5.8), 21.02.2007 Doğanyol Malatya (Mw 5.7), 08.03.2010 Kovancilar Elazig (Mw 6.1), 24.01.2020 Sivrice Elazig (Mw 6.8), 14.06 .2020 Karlıova Bingöl (Mw 5.7) damaging earthquakes have occurred.

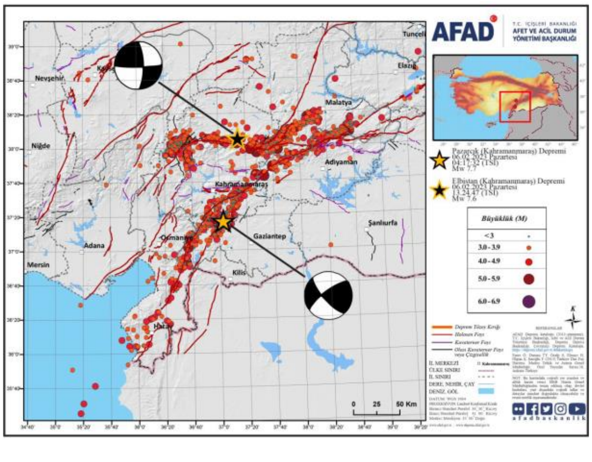


Figure 6. Map showing aftershocks activity of 06.02.2023 earthquakes [16]

On EAFS, on 06.02.2023, at 04:17 Turkey time, Pazarcık (Kahramanmaraş) Mw 7.7 and Elbistan (Kahramanmaraş) Mw 7.6 earthquakes occurred. Oludeniz Fault with a line that includes parts of the Eastern Anatolian Fault System between Çelikhan Pötürge in the northeast of the epicenter earthquake (65 km between Çelikhan-Gölbaşı), Gölbaşı (90 km between Gölbaşı-Türkoğlu), Amanos (110 km between Tür-koğlu-Kırıkhan). He broke the Pomegranate Piece at the North end of the System; The second Elbistan eccentric earthquake was thought to be related to the Çardak Fault and the Doğanşehir Fault Zone (Figure 6).

INVESTIGATION OF RECORDS FROM EARTHQUAKE STATIONS IN MALATYA WITHIN THE SCOPE OF TURKEY BUILDING EARTHQUAKE REGULATIONS

As of January 2019, a total of 1056 earthquake observation stations, 299 of which are velocity and 757 accelerometers, are operated within the body of AFAD Earthquake Deparment.

Although some stations did not work after the Mw 7.7 earthquake, which is one of the 6 February 2023 earthquakes, data were recorded in many stations in our country during the Mw 7.7 and 7.6 earthquakes. Pictures of the nearest accelerometers recording both earthquakes are given in Figure-7.

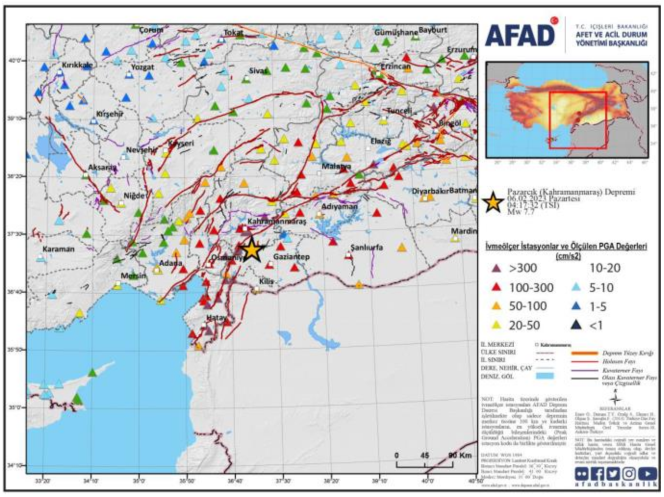


Figure 7. Distribution of nearest accelerometer stations recording the Mw 7.7 earthquake [16]

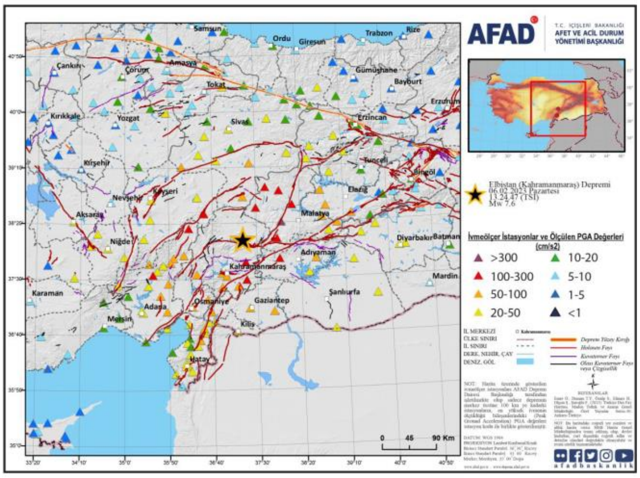


Figure 8. Distribution of nearest accelerometer stations recording the Mw 7.6 earthquake [16]

In Malatya, which is one of the provinces most affected by the Mw 7.7 and 7.6 earthquakes, data were recorded at many stations during these earthquakes. The stations closest to Malatya Center are given in Fig.9.

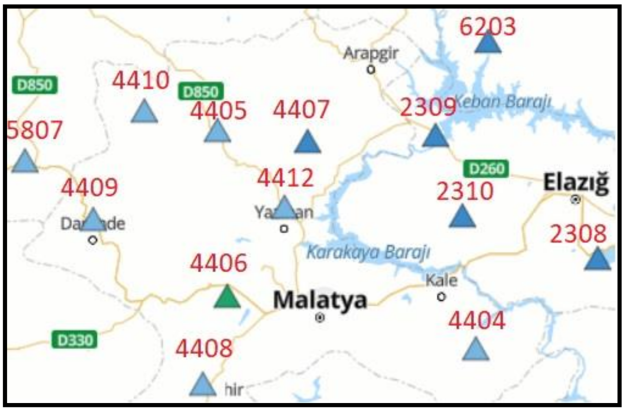
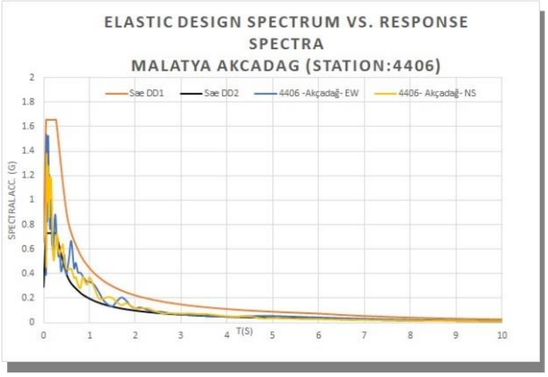
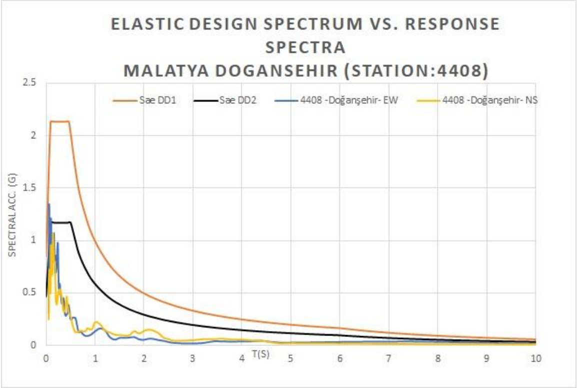


Figure 9. Distribution of accelerometer stations closest to Malatya Center [16]

The reaction spectra created according to the acceleration values received from the stations closest to the center of Malatya, the coordinates of the stations and the graphs created according to the ground are given in Fig.10. As can be seen from these graphs, the reaction spectrum of the earthquake is more than DD2 at most moments and has reached DD1 level at some moments. This is one of the reasons why the destruction of earthquakes is so great.



a)



b)

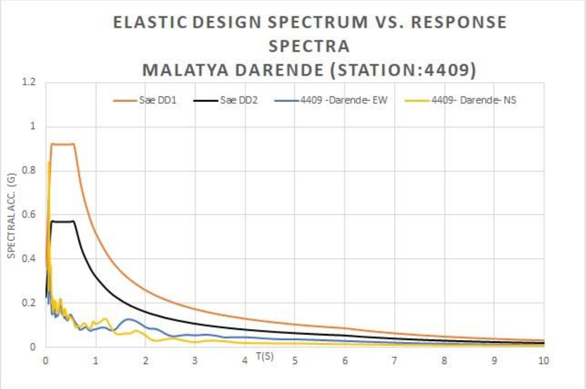
c) 

Figure 10. Comparison of the response spectrum and design spectra based on the acceleration values obtained from a) 4406, b) 4408 and c) 4409 stations [16]

Corner failures of masonry structures in Malatya. Corner failure is usually caused by out-of-plane mechanism effect and wall-to-wall weak connections. This mechanism requires the intersection of walls. Thus, vertical cracks develop, and the wall corners are separated. Weak connections between adjacent walls and the absence of beams cause serious damage. Similar failures are observed at the corners of the roof level due to the decrease in compressive stress and increase in seismic acceleration in the upper floors. In the absence of slab stiffness at roof level, the upper corners are more vulnerable to collapse due to the cantilever-like behaviour [16]. In order to examine these situations, masonry structures at the locations shown in Figure 11 were examined one week after the 6 February 2023 Kahramanmaraş earthquakes.

Figure 11. Locations where investigations took place [17]

In the field, a 2-storey masonry structure shown in Fig.12 in Akçadağ district met the research team at the coordinates 38,38479 N, 37,95899 E. In-plane shear cracks were seen advancing approximately 45º from the window corners of the building. The horizontal bending crack advancing from the window on the right has progressed to the corner wall-wall junction area since there is no vertical beam. Corner collapse mechanism was triggered as a result of in-plane and out-of-plane damage mechanisms, which occurred as a result of the deterioration of the structural integrity as a result of not making the beam at the roof level and directly supporting the wooden roof to the masonry wall.

Figure 12. A 2-storey masonry building (38,38479 N, 37,95899 E) [17]

Figure 13 shows the damage in a 4-storey masonry building in the town of Battalgazi at 38.35371 N, 38.32353 E positions. Also, in Figure 13, two masonry structures with adjacent order and not the same number of floors are shown. The corner collapse mechanism was triggered due to the out-of-plane damage on the perpendicular frontal walls of the rear building from the point where the roof level of the front building ends. The architectural irregularities between the buildings and the horizontal and vertical discontinuities of the load-bearing elements trigger out-of-plane collapse and corner failure mechanisms. The horizontal beams applied at the top of the window in the building at the back preserved the structural integrity thanks to the box-type behavior. In addition, by preventing the corner collapse mechanism from advancing along the floor, it prevented the collapse at the frontal junction.

Figure 13. Two masonry buildings with adjacent layout and not the same number of floors (38,35371 N, 38,32353 E) [17]

Again, the damage distribution in the masonry structure located at 38.35371 N, 38.32353 E positions in Battalgazi district is shown in Figure 14. Shear cracks were observed in the wall parts between the window openings on the ground and first floors of the four- storey masonry building. Corner failure mechanisms have occurred due to the bossage in these wall parts. In addition, another out-of-plane damage was observed on the left side of the main entrance door at the level of the first-floor of the building.

Figure 14. A masonry structure with a corner failure mechanism and shear cracks (38.35371 N, 38.32353 E) [17]

In Figure 15, the damages of a 2-storey masonry structure at 38.35267 N, 38.31155 E positions in Battalgazi district are shown. In the two-storey masonry structure seen, failure mechanism due to lack of roof and diaphragm, collapse of the wall part due to out-of-plane bending mechanism (left), heel bending of the partition wall (middle), wall collapse due to in-plane shear damage (middle)

Figure 15. Damage distribution of a masonry structure (38.35267 N, 38.31155 E) [17]

Another masonry structure, which is very close to the structure shown in Figure 15, is shown in Figure 16. The horizontal bending crack advancing from the window on the right has progressed to the corner wall-wall junction area since there is no vertical beam. Corner failure mechanism was triggered as a result of in-plane and out-of-plane damage mechanisms, which occurred as a result of the deterioration of the structural integrity as a result of not making the beam at the roof level and directly supporting the wooden roof to the masonry wall.

Figure 16. Damage distribution in a single storey masonry building (38.35256 N, 38.31163 E) [17]

Figure 17. A masonry structure that combines the causes of the corner collapse mechanism (38.31279 N, 38.25054 E) [17]

The structure shown in Fig.17, on the other hand, is a masonry structure where the reasons for the corner failure mechanism are together. It has been determined that there is insufficient connection between the roof system and load-bearing walls in the building, which was built with adobe without any engineering service. The front wall of the building collapsed due to out-of-plane bending, which caused separations at the corner joint and the structure was heavily damaged. There are many examples of corner failure mechanisms given so far, and some of the failure modes in Gunduzbey neighborhood are presented in Fig.18.

Figure 18. Corner failure mechanisms in masonry structures in Gündüzbey district [17]

Conclusion. Within this study, first of all, literature information about the corner failure mechanism is presented and some information is given about how numerical and experimental studies are carried out to examine this failure mechanism. Afterwards, corner failure mechanisms that occurred in masonry structures in Malatya after the earthquakes in Kahramanmaraş on February 6, 2023 were examined. In the examinations, it was determined that the corner failure mechanism was caused by insufficient wall-slab connection, insufficient wall-floor connection, insufficient axial load, insufficient material strength, poor workmanship and lack of engineering service. In addition, the corner failure mechanism has been observed in many structures, as is the out-of-plane behaviour, which is the most observed and known failure type in masonry structures, and it has been determined that the corner failure mechanism is triggered by out-of-plane and in-plane failure.

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Məqalə INTERNATIONAL CONGRESS ON ADVANCED EARTHQUAKE RESISTANT STRUCTURES (AERS2023) adlı konfrans materialıdır.