Research Article
Academic Platform Journal of Natural Hazards and Disaster Management
4(2) 2023: 49-64, DOI: 10.52114/apjhad.1400644

Seismic Damages in Masonry Structural Walls and Solution Suggestions

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Received: / Accepted: 5-December-2023 / 21-December-2023

Abstract

Masonry structures are known as an ancient construction technology with a history dating back thousands of years. The main load-bearing members of masonry structures are walls obtained using different materials. These walls, which serve both load-bearing functions and are used to separate spaces, can be thick because they generally have low-strength properties. Masonry structures, which are commonly found in rural areas, are sensitive to earthquake effects and can receive damage at different levels. These masonry buildings, which were generally constructed without any engineering services, were exposed to significant damage under the influence of the Kahramanmaraş earthquake couple that occurred on February 6, 2023. This study examined the damage to the load-bearing walls of masonry buildings in the regions affected by this earthquake couple with the framework of cause-effect relationships and offered solutions. Also, observed wall and material types in the region are mentioned and load-bearing wall damages are represented schematically. Poor masonry workmanship, insufficient use of horizontal/vertical bond beams, use of different wall materials together, heavy earthen roof effect, insufficient corner joints, amount of gaps, and use of low strength mortar have been determined as the main reasons for the damage occurring in masonry load-bearing walls. Performing earthquake-resistant building design principles is critical to minimizing such damage.

Key words: Masonry, Earthquake, Load-bearing wall, Damage, Kahramanmaraş

1. Introduction

On February 6, 2023, Türkiye was affected by two very destructive earthquakes, the epicenters of which were Pazarcık and Elbistan districts of Kahramanmaraş province, and suffered great losses of life and property. While the magnitude of the first of the independent earthquakes that occurred at nine-hour intervals was Mw = 7.7, the magnitude of the second earthquake was Mw = 7.6. This earthquake couple, which occurred on the Eastern Anatolian Fault Zone (EAFZ), one of the main tectonic elements of Türkiye, and was very close to the surface, caused major structural damage in a total of 11 different provinces, especially Hatay, Kahramanmaraş, and Adıyaman provinces.

Two immense earthquakes, independent of each other, caused significant structural damage to masonry buildings widely preferred in village and rural areas. Masonry buildings are economic

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structures constructed using regional materials without any engineering services. The properties of masonry structures formed by combining natural, unprocessed, and/or processed materials with the help of a mortar may vary regionally. There is no frame system in such structures. The loads acting on the structure are transferred to the ground with the help of load-bearing walls, which make up the structure and whose thickness is much greater than in reinforced concrete structures. These walls are also used to divide the building into sections and to surround the usage area of the building. Since there are no columns in these structures, the vertical load-bearing elements are walls. For various reasons, the earthquake performance of masonry structures, which are widely used in rural areas today, is quite low due to the poor material properties used. Not having sufficient ductility capacity makes it difficult to dissipate energy, especially under the influence of horizontal loads such as earthquakes, and may cause sudden structural damage in such structures. At this point, the careful application of earthquake-resistant building design principles in the construction of walls, which are the main load-bearing structures in such structures, will ensure that the damage levels are lower [1-10].

Examining the cause-effect relationship of damages occurring in buildings with different load-bearing systems after each earthquake reveals the significance of earthquake-resistant building design principles. There are many studies on the earthquake performances of historical buildings built in masonry style, especially masonry structures, which are the most preferred building stock in rural areas, their reinforcement, and the structural damages that occur in such structures after earthquakes [11-24]. The studies generally include observational examination results about the damages caused by earthquakes in such structures and structural analyses of the numerical models created. There are some studies conducted after the 2019 Albania [25, 26], 2012 Emilia-Romagna (Italy) [27, 28], 2020 Zagreb [29, 30], and 2017 Puebla-Morelos (Mexico) [31, 32] earthquakes. There are many studies on the damage to masonry structures following earthquakes in Türkiye. These are some of the studies that include the evaluation of damage to masonry structures after the 2007-Ankara [33], 2010-Elazığ [34], 2011-Van [35, 36], 2019-Elazığ [37], 2004-Ağrı [38] and 2020-Elazığ [39] earthquakes. In addition, studies on the effects of the Kahramanmaraş earthquake couple on structures with different types of structural systems have found their place in the literature [40-52].

These walls, created using different wall materials, directly affect the earthquake performance of the buildings. Within the scope of this paper, the action of the 06 February 2023 Kahramanmaraş disasters, which are known as the disaster of the century for the country and caused thousands of buildings to be damaged at different levels, on the load-bearing walls that form masonry structures were examined. After the earthquakes, damage situations were tried to be discussed in detail within the framework of civil and earthquake engineering with the help of data obtained as a consequence of field observations made by the authors. The obtained data were subjected to a meticulous comparison in line with the rules specified in the earthquake regulations. In light of all this data, solution suggestions for load-bearing walls and existing masonry structures have been tried to be presented.

2. Materials and Method

2.1. 06 February 2023 Kahramanmaraş Disasters

Türkiye is located in the Alpine-Himalayan orogenic belt, which is very seismically active. While the Arabian and African plates are moving northwards towards the Eurasian plate, the Anatolian microplate is getting stuck in between and moving westward due to the resistance of the Eurasian Plate from the north. This situation caused active faulting along the right-lateral

North Anatolian Fault Zone (NAFZ) and the left-lateral East Anatolian Fault Zone (EAFZ). An earthquake with a moment magnitude (Mw) of 7.7 occurred on the Eastern Anatolian fault at 04.17 local time on February 6, 2023, near Pazarcık (Kahramanmaraş) at a depth of 8.6 km. Essentially, this earthquake was the beginning of a series of large earthquakes that occurred one after the other. Because immediately after the first earthquake, there was another aftershock with a magnitude of Mw = 6.6. Later, a new main shock with a magnitude of Mw = 7.6 hit on the same day, a fourth shock with a magnitude of ML = 5.7, a fifth shock with a magnitude of Mw = 6.0, and a sixth main shock with a magnitude of Mw = 6.4 on February 20, 2023 (Figure 1). The earthquake, centered in Pazarcık, ruptured for 350 km, and the second earthquake ruptured along approximately 160 km of the Sürgü fault [53]. The earthquake affected millions of people in 11 different provinces. In this event, serious damage to infrastructure, including loss of life and collapse, was recorded, and 14 million people were affected by this earthquake. Accordingly, as of March 6, 2023, approximately 50,000 people were killed, nearly 110,000 people were injured, more than 500,000 buildings were damaged and approximately 40,000 buildings completely collapsed.

Previous earthquakes along the EAFZ include the 1789 Palu (M=7.2), 1795 Pazarcık (M=7.0), 1872 Amanos (M=7.2), 1874 Palu (M=7.1), 1875 Palu (M=6.7), 1893 Erkenek (M =7.1), 1971 Karlıova (M=6.6) and 2020 Pütürge (Mw=6.8) earthquakes. These earthquakes occur along successive segments, and there are 7 segments along the EAFZ (Figure 2). One movement sets off the sequence of earthquakes. The initial earthquake (Mw = 7.7) struck near the northernmost point of the Dead Sea Fault Zone (DSFZ) and inside the Eastern Arm of the Fault Zone (EAFZ). Because of the region's intricate tectonic structure, earthquakes frequently happen close to one another. It transmitted stresses to the next segment following each earthquake that occurred in its segments because of the left-lateral strike-slip and around 580 km long EAFZ nature [54–57].

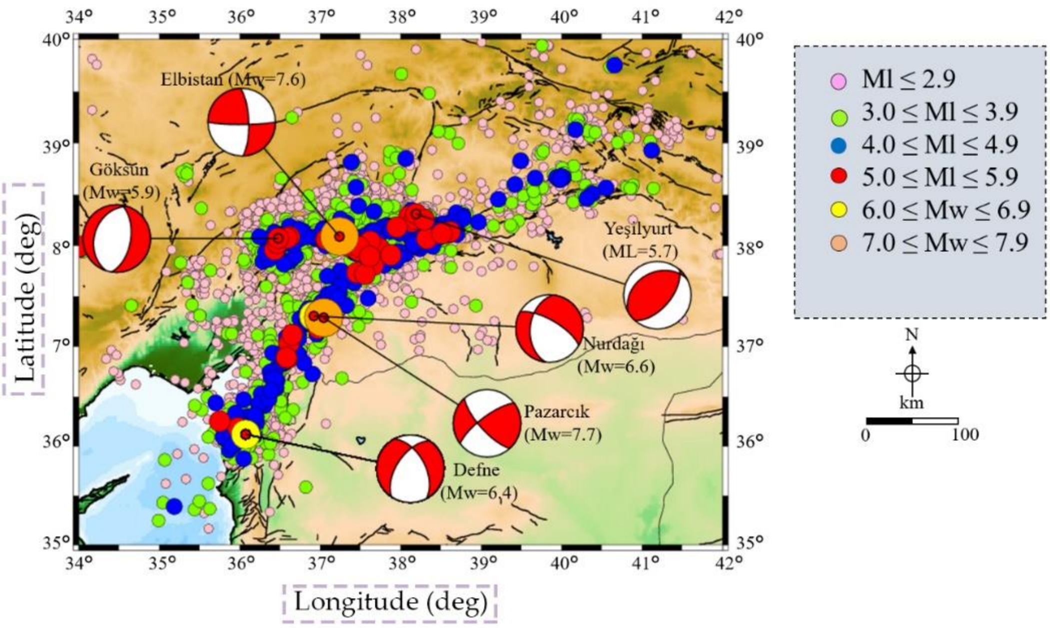

Figure 1. Distribution of earthquakes that occurred on 06 February 2023 and the following days [54]

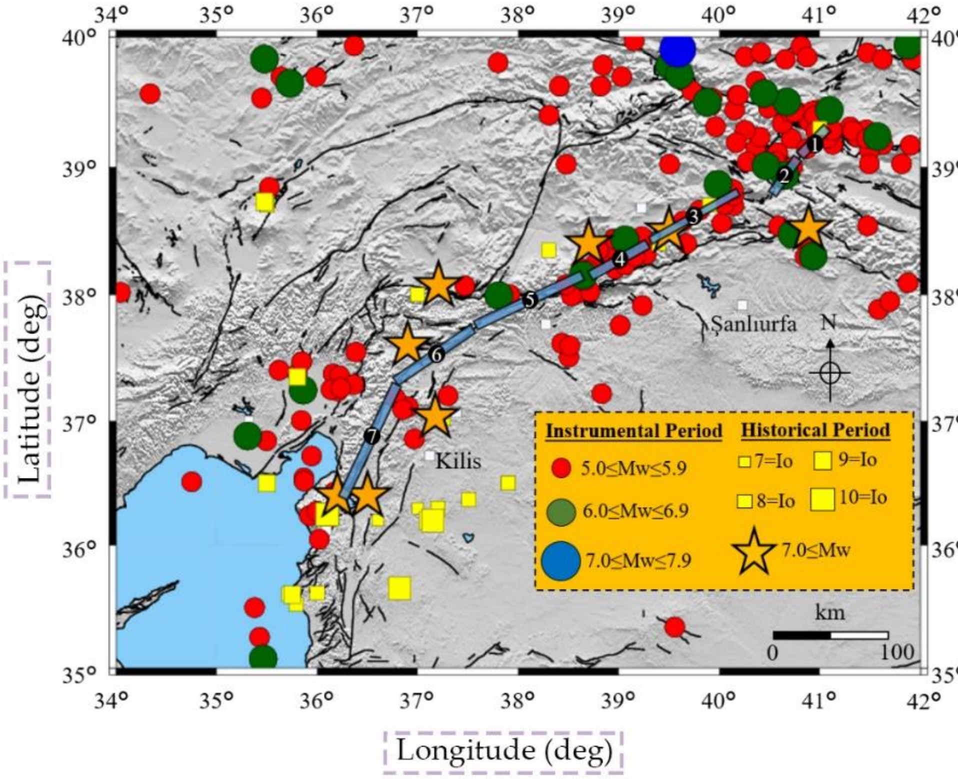

Figure 2. Distribution of instrumental (Mw>5.0) and historical earthquakes occurring along the EAFZ [54]

The PGA value recorded during the Kahramanmaraş Pazarcık Earthquake was obtained at station 4614. The station is located at latitude 37.48513 and longitude 37.29775, with PGA values of 2165.62 cm/s², 2178.72 cm/s², and 1951.68 cm/s² in the N-S, E-W, and U-D directions, respectively. The acceleration-time graphs for the station are presented in Figure 3. The response spectra calculated from the recorded ground motions are compared in Figure 4 with the horizontal and vertical elastic design spectra defined in the TBEC-2018 seismic hazard map for the same station. The comparison is made for DD-1 (return period of 2475 years), DD-2 (return period of 475 years), and DD-3 (return period of 72 years), earthquake ground motion levels. Upon examination of the figure, it is observed that the spectral accelerations of the actual earthquake at station 4614 exceed the design spectra for DD-1 and DD-2 earthquake levels, considering poorly separated, moderately stiff rocks (soil class ZB) as ground conditions.

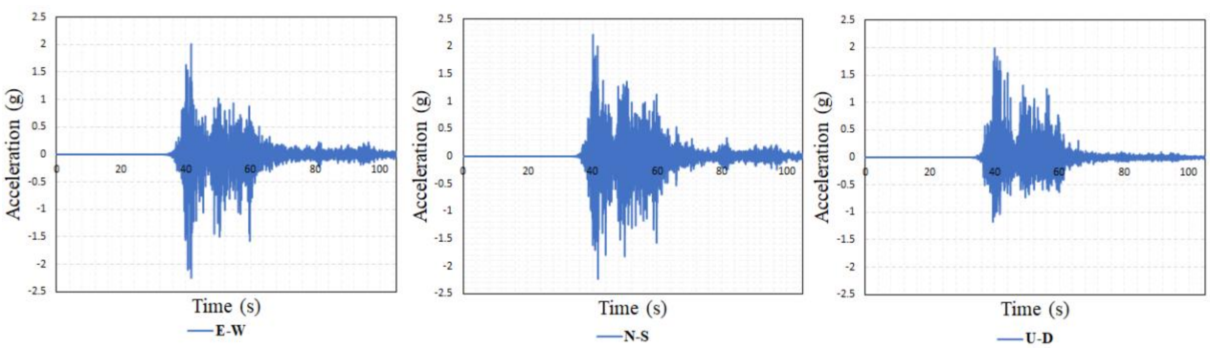

Figure 3. The recorded ground accelerations of Kahramanmaraş earthquake at 4614 station

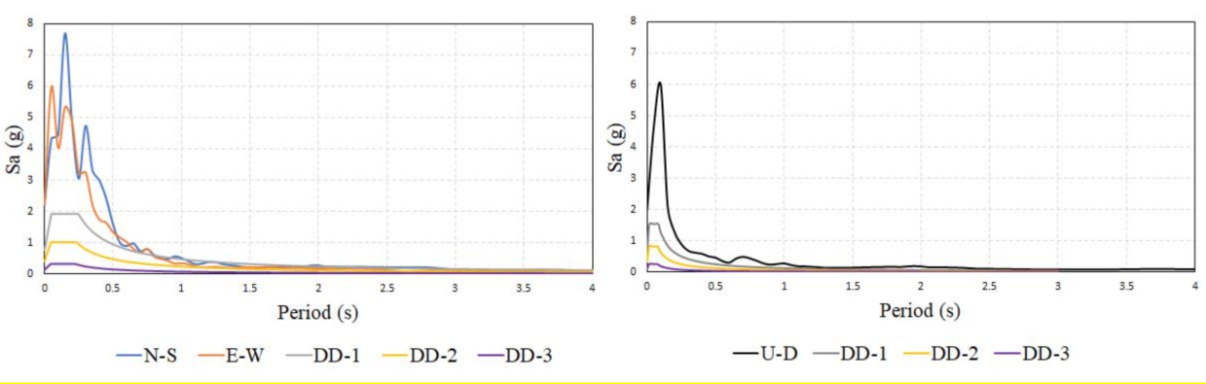

Figure 4. Comparison of response spectra

2.2. Damages Occurring in the Bearing Walls of Masonry Structures

Masonry structures are built economically using local materials and workmanship, and it is a construction system still used today, especially in rural areas. In such structures, the walls are kept thicker and the loads are transmitted to the ground through these walls. Damages to the load-bearing walls, which are the most important members of masonry structures, may cause the structure to be considered severely damaged and cause total collapse of the structure. The presence of factors in these elements that will negatively affect earthquake resistance directly affects the level of damage that will occur. Within the scope of this study, the load-bearing wall damages in masonry structures, which are the dominant building stock of rural areas, were examined in detail after the February 6, 2023 Kahramanmaraş earthquakes. It was observed that adobe, adobe+briquette, briquette, stone and double-layered stone were used as wall materials in the masonry structures in the region, as shown in Figure 5.

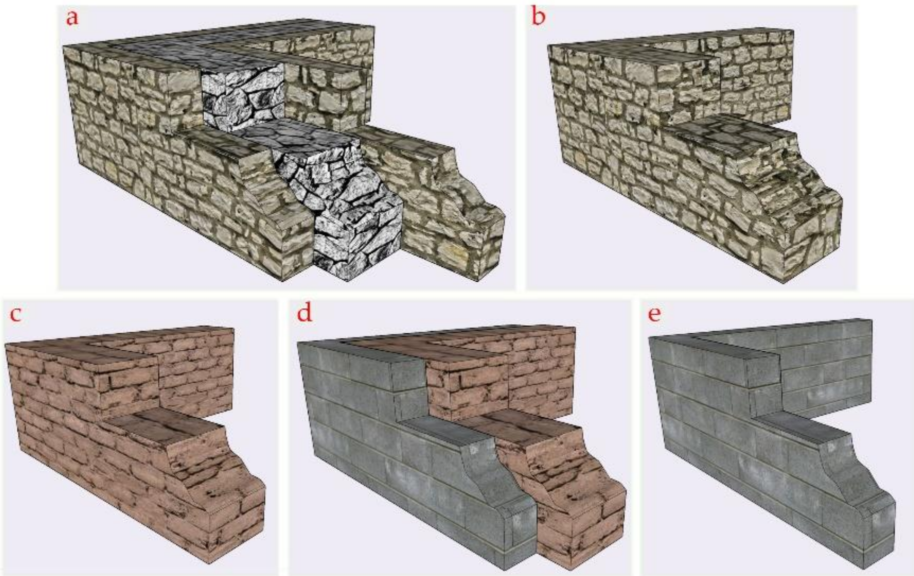

Figure 5. Observed wall and material types a)double-layered stone b)stone c)adobe d)briquette+adobe e)briquette

One of the elements that will affect the earthquake performance of masonry structures is forming the corner connections rigid and strong. One of the damages observed after earthquakes, especially in rural areas, is separation damage in the wall-corner joint areas. The level of damage was negatively affected by the lateral stresses resulting from heavy earthen use in the masonry structures built in these regions. Additionally, during earthquakes, forces are exerted on structures in both principal directions. Under this two-way loading, the condition of the corner of the masonry structure shows different movements and pushes each other. If the walls are not well connected at the corner and there is no bond beam or roof slab, the walls will push each other at the corner, causing wall separation damage [4, 58]. Examples of such damage are shown in Figure 6.

Figure 6. Wall separation at corners of the structures

It is known that window and door gaps in masonry structures intercept the load-bearing walls from appropriately transferring bending and shear stresses [59-61]. Door and window openings reduce the cross-sectional area of load-bearing walls in masonry buildings, causing shear and bending stresses to increase. This situation reduces the capacity of the wall and reduces the strength of the structure under the influence of forces such as earthquakes. Such damages are frequently encountered because gaps do not meet the boundary conditions specified in earthquake codes. Examples of such damage are shown in Figure 7.

Figure 7. Damages at window corners

Failure to create appropriate joints in both directions at the corners of the load-bearing walls may reduce the rigidity of the walls and lead to further damage to the buildings. As a consequence of the observations made in the field after the Kahramanmaraş earthquakes, the failure to create appropriate joints in these areas caused out-of-plane wall damage at the corners. Examples of such damage are demonstrated in Figure 8.

Figure 8. Examples of out-of-plane wall corner damage

One of the other types of damage encountered is the falling of the outer coverings of the wall materials used in masonry structures, which are used to make their appearance smoother. It has been determined that exterior coatings made using low-strength mortar are generally subject to out-of-plane behavior. Examples of such damage are shown in Figure 9.

Figure 9. Falling of exterior materials

One of the damages frequently observed in masonry structures in earthquake zones is the out-of-plane movement of load-bearing walls. In addition to the low mechanical properties of the wall and connection material used, inadequate wall-wall connections cause out-of-plane movements on the walls, causing damage. Examples of such damage are demonstrated in Figure 10.

Figure 10. Example of out-of-plane movement on load-bearing walls

Due to the fact that masonry buildings do not have any frame system and the low strength properties of the materials used in the construction of the walls, their wall thickness increases significantly compared to reinforced concrete structures. Wall layers are created to provide this thickness. Inadequate connections between layers and the combined use of wall materials with different properties caused these layers to separate under the earthquake effect and receive damage at different levels. Examples of such damage are shown in Figure 11.

Figure 11. Examples of damage caused by inadequate connections between layers

In masonry structures, using wall materials that are not regular in shape, incorrect wall material placement, poor masonry workmanship, and unsuitable connection mortar have also caused various levels of damage to the load-bearing walls. Examples of such damage are demonstrated in Figure 12.

Figure 12. Examples of wall damage caused by various reasons

3. Results

The Kahramanmaraş earthquakes of February 6, 2023, called the disaster of the century for Türkiye, caused great destruction in a very large region. Significant damage has occurred in buildings with different structural systems. Various levels of damage have occurred in masonry structures, which are widely used especially in rural areas. This study focused on the damages occurring in masonry walls located in the earthquake zone and the damages occurring in load-bearing walls, which are the most important elements of masonry structures. As a result of field observations, the damages occurring on these walls were evaluated. It is thought that photographs taken from the region provide an important resource to provide a general understanding of these damages. Damages have been observed in various forms such as out-of-plane deformations at corner points, irregular use of wall materials, low or insufficient strength of the wall materials used, and out-of-plane movements on the walls. These results emphasize the importance of measures to be taken to improve the earthquake resistance of masonry structures in rural areas exposed to earthquakes and to make them durable after the earthquake. Schematic representations of the structural damages resulting from the evaluations are shown in Figure 113.

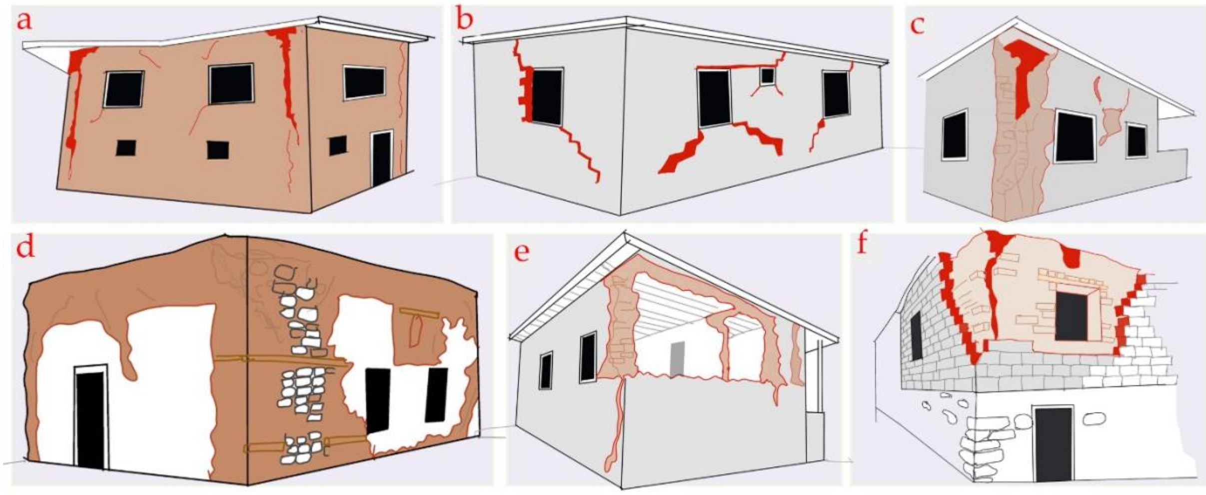

Figure 13. Schematic representation of load-bearing wall damages in masonry structures a) separation at corners b) window corners damages c) out-of-plane wall corner damages d) Falling of exterior materials e) out-of-plane movement f) inadequate connections

4. Discussion

Walls used to determine external boundaries and divide spaces in masonry structures also serve as load-bearing members. It works on the principle that the loads affecting such structures are carried through these walls and transferred from there to the foundation and ground. In rural areas of Türkiye, masonry buildings are widely preferred because their materials and labor are easy to obtain and are economical. The earthquake performance of these structures, which were built haphazardly by local craftsmen and workers without any engineering services, remains quite low. For such buildings, where earthquake-resistant building design principles are rarely used, it is important to apply the building control system applied to the urban building stock to such buildings. Obtaining the necessary engineering services and showing the necessary sensitivity during the construction phase is one of the important steps that can be taken to minimize the damages that may occur in such structures. In addition, the necessary work should be carried out quickly, especially on the existing masonry building stock, and the masonry structures damaged during the earthquake should be demolished, but the necessary strengthening operations should also be carried out for masonry structures with historical value. As a result of the evaluations, making demolition decisions regarding masonry structures whose earthquake performance is not sufficient will be one of the measures that can be taken.

5. Conclusions

As a result, the causes of load-bearing wall damage in masonry structures are listed below.

- During the building's design and construction stages, no engineering services are provided.

- Failure to apply earthquake-resistant building design principles
- Insufficient connection problem at the wall corner
- Not using bond beams that should be used horizontally and vertically.
- Heavy earthen roof effect
- Poor masonry workmanship
- Presence of large door and window openings,
- Use of low-strength materials,
- Wrong formation of joints,
- Combined use of materials with different mechanical properties
- Use of wall materials that are not regular in shape,
- Incorrect wall material placement,
- Unsuitable connection mortar
- The technique of masonry construction is about to be forgotten, and there are no longer any fresh experts being trained.
- Re-evaluating the possibilities of inter-usability of conventional and contemporary methods.
- Standardizing the usability of local materials in construction and controlling random use.

Acknowledgements

We would like to express our gratitude to Civil Engineer Mr. Mehmet Şakir Güngür, Civil Engineer Mr. Mutlu Günay, and Civil Engineer Mr. Ömer Faruk Avcı who made significant contributions to the study.

Conflict of Interest

The authors declare no conflict of interest.

Author Contribution

E.I, E.A, A.B., F.A. and R.I contributed to the design and implementation of the research, to the analysis of the results and to the writing of the manuscript.

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