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Structural evaluation of traditional masonry buildings during the February 6 - 12, 2017 Ayvacık (Çanakkale) earthquakes in Turkey

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Abstract

Throughout history, the town and environs of Ayvacık, a district of Çanakkale in western Turkey, has been home to a traditional style of architecture that represents the integration of cultures originating from different geographies. The medium-sized and major earthquakes that occur periodically in the region constitute a threat to the sustainability of this traditional residential architecture. Four moderate earthquakes having magnitudes of between 5.2 and 5.3 struck the epicenter of Gülpınar - Ayvacık (Çanakkale) over the period February 6 -12, 2017. These earthquakes were strongly felt in the region and in the rural areas, unreinforced stone masonry house structures suffered significant damages. In this study, seventy-two damaged traditional houses were investigated in Yukarıköy district of Ayvacık based on onsite observations, and the types of damage and their potential causes were evaluated according to the data gathered. The reasons for the eleven types of damages were the irregularities present in the formation of the stone blocks of external walls, the sizes of the stone blocks and the irregularities in masonry detailing, the use of weak mud mortar, the lack of tie beams at the floor and roof levels, and the weak connections between different internal wall systems and external walls.

Keywords
Ayvacık earthquake, Earthquake damage, Masonry buildings, Traditional Ayvacık house, Traditional construction techniques.

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1. Introduction

The North Aegean and South Marmara Regions of Turkey are areas in which many civilizations have existed over the centuries, leaving behind the architectural traces of various different cultures. The Biga Peninsula, in particular, has witnessed the interaction of eastern and western cultures from prehistoric times up to the present. Throughout history, the town and environs of Ayvacık, a district of Çanakkale located in the Biga Peninsula, has been the site of the integration of cultures originating from different geographies, and it is one of the rare areas in the world in which this cultural diversity has been preserved to the present day (Özdemir, 2008). The multitude of data harvested from excavation and surface explorations of prehistoric settlements point to a rich cultural history in the area. These settlements are largely concentrated along the coasts and they openly reveal the effective role Ayvacık played in the interaction of North and West Anatolia and Europe in prehistoric periods (Kocabıçak & Pilehvarian, 2017).

The interchanges of the different coexisting cultures and the footprints of past societies had a great impact on the architectural and structural formation of traditional houses. Besides the availability of local materials, the building techniques used by artisans also influence the architectural and structural configuration of houses and are integral to the emergence of their characteristic features. There are similarities between the architectural and structural features of houses in past settlements and the traditional structures that exist today along the Ayvacık countryside. Earthquakes, both moderate and major, occur in this region at periodic intervals. These earthquakes have destructive and devastating effects on houses and present an important threat to the sustainability of the traditional residential architecture that is so much a part of local architectural heritage.

Turkey is under the influence of three main active seismic belts, namely those of Northern Anatolia, Southeastern Anatolia and Western Anatolia. In the moderate earthquakes that have hit the country throughout history, it has been observed that buildings with a framework of reinforced concrete (RC) in the city centers have suffered slight damage while buildings of masonry in the rural areas have sustained heavy damage and loss of human lives. Scientific studies on these earthquakes have reported that structures using local materials such as stone, mud-brick, and terra cotta have been built without supervisory engineering services. When the possibility of future earthquakes is considered, it is quite evident that structures of similar quality in the rural areas pose the same potential for devastation (Gulkan & Sucuoglu, 1989; Bayraktar et al., 2007; Celep et al., 2011; Sayın et al., 2013; Sengel & Dogan, 2013; Doğan, 2013; Yazgan et al., 2016; Hao et al., 2016; Giaretton et al., 2015; Livaoğlu et al.; 2018; Ismail & Khattak 2019).

Northwestern Anatolia and the North Aegean Sea are the most prominent areas of seismic activity and deformation between the Eurasian and African tectonic plates. The region is under the influence of both the strike-slip tectonic regime that is the general characteristic of the North Anatolian Fault Zone (NAFZ) and the divergent regime of Western Anatolia (Özden et al., 2018). The most destructive earthquakes occurring in the instrumental period (after 1900) were the Aegean Sea Earthquake (M_W=7.2) of 1981, the Ayvalık-Çanakkale Earthquake (M_W=7.0) of 1919, and the Edremit Earthquake (M_W=6.8) of 1944 (Figure 1).

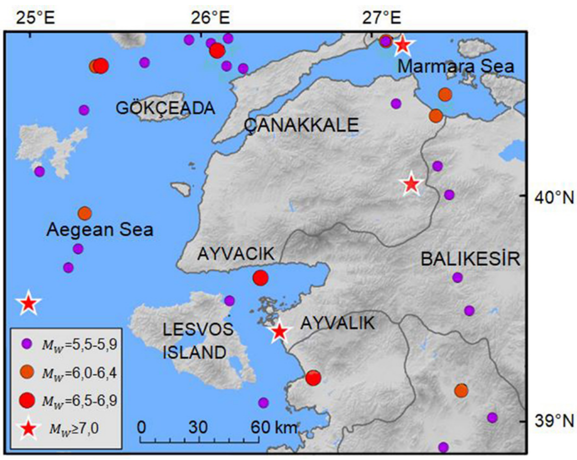


Figure 1. *Instrumental earthquake effectiveness of earthquake region (M≥5.5 after 1900) (adapted from KOERI, 2014).*

In the period February 6 - 12, 2017, four earthquakes having magnitudes of 5.2 and 5.3 took place at the epicenter of Gülpınar-Ayvacık (Çanakkale). In this study, seventy-two damaged houses were investigated in the Yukarıköy district of Ayvacık based on onsite observations. Assessments have been made based on the data collected as to types of damage, causes and the prevalence of the types of damage according to the degree of damage sustained. The effect of the chain of four moderate earthquakes and of magnitudes of approximately M_W=5.2 and 5.3 on the rural architecture in the period of six days was different from the impact wielded by previous earthquakes. The evaluation of these effects is important in ensuring that the structures of masonry built from local stone materials in these rural areas are made to withstand earthquakes of this kind.

2. Traditional Ayvacık houses

2.1. Historical development of the residential architecture of the region

The Neolithic Age (8000-5500 B.C.), a time in which man left behind a nomadic lifestyle of hunting and gathering, putting in its place a life connected to the soil, is a significant period in terms of human history. Village settlements from that era still exist in Çanakkale (Özdemir, 2008). The only settlement representing the Neolithic Age in Ayvacık can be found at Coşkuntepe, situated on a natural hillside close to the village of Bademli. First populated around 6000 B.C., the Neolithic settlement of Coskuntepe as well as the Gülpınar settlement, populated around 4500 B.C. and representing the Chalcolithic period, are the most prominent areas of habitation in the region of Ayvacık that date back to prehistoric times. The Early Bronze Age witnessed the emergence of some major coastal settlements along the west and south shores of the Biga Peninsula. These settlements represent the beginning of the Early Bronze Age and are generally classified in archeological literature as belonging to the era of Troya I (2900-2600 B.C.) (Figure 2). The resurgence in the population of the south coastal region of Ayvacık coincides with the seizure of Assos by the Lydians in 560 B.C. Assos in that period became a major city in the Gulf of Edremit and also the most powerful. Assos was continuously inhabited over the course of the Byzantine era and was used as a center of the episcopate. During this period, various major ports were built by the Christians along the southern shores of Ayvacık (Serdaroğlu, 1996; Aslan, 2008; Aslan, 2012). The area, which had been under Roman rule up until 330 A.D., then passed into Byzantine hands (Deniz, 1998). A great many Turkmen tribes settled in the area in 1092 and in 1288, following the victory of Lemnos, it came under Turkish rule. In 1335, the Ottomans took over and it has remained under Turkish sovereignty uninterruptedly since that time (Gadanaz & Orhan, 2008). From 1924 to 1928, various population exchanges brought compulsory refugees into Gelibolu and Çanakkale. During these transfers, locally settled Greeks went to the opposite shores and the Turks coming in from Crete and Lesvos settled in the places that the Greeks had vacated. A large part of the people being transferred in these exchanges settled in the vacated villages of Ayvacık (Serdaroğlu, 1996).

The town and environs of Ayvacık has been home to a traditional style of architecture that represents the integration of cultures originating from different geographies. The history of residential architecture in the area starts from the settlement of Gülpınar, dated to circa 4500 B.C. Collected data have shown that the walls of the houses in this settlement were made from rubblestone, with corners constructed

Figure 2. *Historic settlements in Ayvacık and its environs.*

of blocks of cut stone (Özgünel & Kaplan 2011). Similarly, it can be said that the flat-roofed stone houses of simple, rectangular form in the settlements of Gökçeada Yenibademli and Troya, dated to circa 3000 B.C., represented the same tradition (Hüryılmaz, 2002). The use of similar building materials and techniques observed in Zagora, dated to the Iron Age, circa ninth century, B.C. is evidence that building techniques have followed a particular traditional pattern in the region and date back to the distant past (Kocabıçak & Pilehvarian, 2017). In the 10th and 9th centuries, B.C., residential architecture on the Aegean islands relied completely on materials of masonry. It has been asserted that this was a matter of necessity because of the geological formation of the land (Eran, 1994). The use of large blocks of stone at the corners of walls (elbow stone) to ensure strength and stability was a largely common application in the area, though not completely in the entire region. It is said that stone was used in the residential architecture of the Western Aegean and Mediterranean region in the Early Iron Age (Eran, 1994).

2.2. Characteristics of today's Ayvacık houses

The houses in the region of Ayvacık are one or two-storied and are evenly situated on a rectangular or square plan, all of them having been built in the masonry structural system in which local stones have been used. The stone blocks used in the buildings are made of ignimbrite or andesite, which is widely found in the region. In erecting the load-bearing walls, the stone blocks are bonded to each other with mud-based mortar. The wall blocks are formed from cut stone and rubble stone. The internal walls of some of the one-storied houses are constructed from manufactured fired clay brick and have a wooden framework that cannot endure the load of either floor or roof. In general, two types of stone forms have been used in the walls. Larger cutstones called "dirsek taşı" have been used to increase the endurance of the building and its openings, while smaller stones have been used in-between to make up the outer surface. A technique specific to the region known as "ırama" has been used in the masonry bonding. The inner and outer surfaces of the walls have been filled in with a mixture of mud and dried weeds. Tie beams have not been used in many of the load-bearing walls or in the intermediate areas. There are rare examples of houses where a timber tie beam has been employed. Some of the roofs of the houses are flat and have been covered with clay material while some are in the form of a hipped roof that is covered with brick and slopes down in all four directions. The roof covering is made of clayey-earth, which is called "çorak" (wasteland) in the region (Kocabıçak & Pilehvarian, 2017). Çorak is a type of earth in which nothing can be cultivated. The components of the roof construction are made of wood. In the same way, the floor construction and covering materials of the two-storied houses are also made of wood. The main load-bearing timber beams of the roof and floor construction are directly and uniaxially supported on and inside the stone walls. Figure 3 depicts a structure with a hipped roof covered with brick and sloping down in all four directions and the cross-section of a construction system with a flat clay-covered roof.

The characteristics of Ayvacık houses can be seen also in the regions of the Northern Aegean and Southern Marmara, in the traditional residential architecture of Foça, Lesvos, Gökçeada and the Aegean Islands. These houses are built on a square plan from two types of stone. The external walls have unmortared outer surfaces and mortared inner surfaces. Window dimensions are in the ratio of 1:1.5, and other common characteristics include the use of a double-winged window system of woodworking and wall niches. The cross-sectional arrangement of the loadbearing external walls of the houses in this region are formed of rubblestone plastered one on top of the other and bonded in two rows. The bonding of the two rows is not carried out with large stones or through stones but only with mud mortar. This type of coursed stone building has a long history that can be traced back to the Age of Antiquity. While the walls of temples were

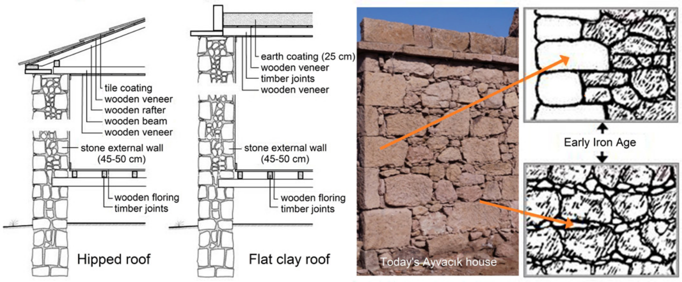


Figure 3. *System cross-section of today's Ayvacık houses and similarities of wall bonding technic between traditional Ayvacık houses and the houses of the Early Iron Age.*

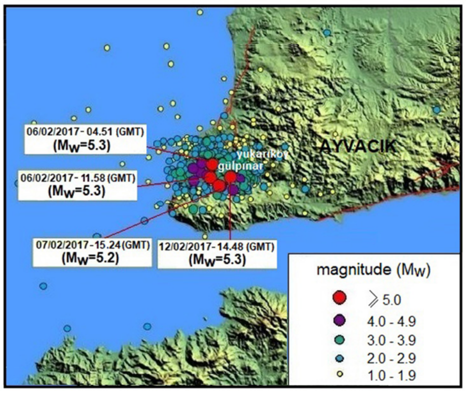


Figure 4. *Distribution of aftershocks of February 12, 2017 Çanakkale-Ayvacık earthquake epicenter (M_W=5.3) and the earthquake of February 6, 2017 (adapted from AFAD, 2017; KOERI, 2014).*

made from rectangular stone blocks, through stones were used in building high walls to ward off the risk of collapse (Saner, 1995; Kolay, 1999).

The houses in today's Ayvacık exhibit various similarities to the historical residential architecture of the region. These similarities point to historical continuity and the most significant can be seen in the system of masonry wall bonding used in external walls. The large stones (elbow stones) used in the Early Iron Age in Western Aegean and Mediterranean houses to ensure strength and stability were widely used, albeit not completely throughout the region (Eran, 1994). Designs were formed on the surface of the wall by placing small stones in between the rubblestone (Figure 3).

3. The Ayvacık earthquakes of February 6-12, 2017

In the period February 6 - 12, 2017, four earthquakes having magnitudes of 5.2 and 5.3 took place at the epicenter of Gülpınar-Ayvacık (Çanakkale). On February 6, 2017, an earthquake of M_W=5.3 occurred at the epicenter of Gülpınar-Ayvacık (Çanakkale) at 06:51 (04:51 GMT) local time. The earthquake was considered shallow, striking at a depth of approximately 6 km. It was felt primarily in Çanakkale as well as in Izmir, Bursa, and İstanbul. On February 6, 2017, at 13:58 (11:58 GMT) local time, a second earthquake of M_W=5.3 was strongly felt in the region and caused panic among the population. This was again created by a normal strike-slip fault. On February 7, 2017 at 17:24 (15:24 GMT) local time, the region was hit with a third earthquake of M_W=5.2. This too was strongly felt in the region and the masonry buildings that had been damaged in the first earthquake were further ravaged. On February 12, 2017 at 16:48 (14:48 GMT) local time, a fourth earthquake of M_W=5.3 struck (Figure 4). This earthquake was created by a normal strike-slip fault (KOERI, 2014).

The assessment of the damage in the area revealed destruction in a total of 24 settlements, particularly in the area of Yukarıköy in the district of Ayvalık, with 480 heavily damaged/collapsed houses, 392 slightly damaged houses, 1 heavily damaged spa, 6 heavily damaged mosques, 75 heavily damaged barns, a total of 1008 structures in ruin (AFAD, 2017).

4. Classification of the house in relation to structural damages

According to the general degrees of damage cited by the European Macroseismic Scale (EMS 98) and the Earthquake Regulations of Turkey, unreinforced masonry buildings sustained five different degrees of damage–slight, moderate, heavy damage, partial or complete collapse (Grünthal, 1998; TEC, 2007). Cracks of a width of less than 10 mm form in the load-bearing walls of slightly damaged structures of masonry. Shear cracks of a width of 10-25 mm in X formation occur in structures of masonry that have been moderately damaged. In heavily damaged buildings of masonry, the width of the cracks is over 25 mm. The load-bearing walls in these structures can sustain vertical displacement, ruptures at corner joints, delamination due to vertical loads, surface ruptures or partial collapse along the plane. In masonry buildings that have partially collapsed, a large part of the load-bearing walls tumble along the plane or collapse in disintegration. Additionally, partial collapse can be seen in roofs and floor structures. In masonry buildings that have completely collapsed, all of the load-bearing external walls lose their load-bearing strength (Bayülke, 1992).

In Yukarıköy, it was determined that the earthquake damaged seventy-two structures in different degrees of impact. The damage was classified in five categories: slight, moderate, heavy, partial collapse and complete collapse. It was observed that the external walls of the slightly damaged houses had one-directional cracks of a width of less than 10 mm. When the forces of the earthquake hitting the structure were parallel to the wall, the cracks were seen to be slanted; when they had a perpendicular impact, the cracks were horizontal and vertical (Figure 5a). The external walls of moderately damaged houses had cracks in the shapes of X'es that measured 10-25 mm (Figure 5b). Some parts of stone walls that were forced to bend out of plane showed signs of delamination and partial collapse. Large cracks of more than 25 mm were observed in the load-bearing internal and external walls, in the body of the walls and at the wall connections of the heavily damaged houses. In addition, it was also determined that the joining points of these load-bearing walls displayed vertical ruptures, divergences from the vertical and partial collapse (Figure 5c). In partially collapsed houses, it was seen that the load-bearing external walls had been partially wrecked or wrecked along the length of the plane and that because of this, the roof or intermediate floor structure had also partially caved in at these regions (Figure 5d). It was determined that totally demolished houses exhibited ruptures at the corner joints of their load-bearing external walls or had been fragmented in the middle of the structure (Figure 5e).

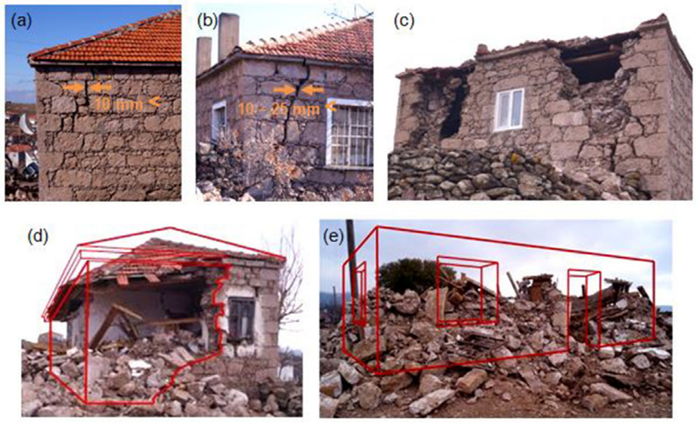


Figure 5. *Building examples of the masonry structure according to the degree of damage: slightly damaged (a), moderately damaged (b), heavily damaged (c), partially collapsed (d), and completely collapsed (e).*

5. Types of damages and an assessment of causes

The rural houses in Yukarıköy were subjected to horizontal earthquake forces from different directions and depending upon their specific structural characteristics, suffered different types and degrees of damage. The lesser durability of the bonding mortar used in masonry systems compared to stone blocks plays a role in the behavior of collapse. Figure 6 shows a section of a partially collapsed load-bearing external wall, where the cracks, disintegration and the wall building system that ultimately caused the wreckage can be seen. The reasons for such types of damage lie in the rubble stone form of the stone blocks and their irregular sizes, the irregularities in the building system, and the unsuitability of the mortar that has been used to bond the rubble stones together. Also, the spaces in-between the rubble stone blocks have been filled in with pebbles and earth, a practice that increases the irregularity of the wall-building system. These small particles of stone have no bonding response and very easily separate from the wall as the result of a vibration, leaving spaces between the larger stones. As can be seen in the closeup of the section of the wall in Figure 6, the mud mortar in section 2 has cracked from the impact of the earthquake and has resulted in a vertical cavity in the midsection. Because of the lack of a tie beam, the partial divergence, disintegration caused by ruptures in the external wall has separated on a vertical plane into three separate zones. Another important reason for the occurrence of this type of damage was the failure to position the rectangular binding stones at regular vertical intervals on the horizontal plane and along the width of the wall. The spaces formed here constitute the first steps in the occurrence of damage that gradually progresses to the collapse of load-bearing walls. In Figure 7a can be seen the partial rupture and flaking of the load-bearing external wall of a structure that has sustained such damage. The lack of a tie beam at the level of the roof on the external wall is also a major cause for rupture and disintegration. It was observed that the impact of the earthquake also caused the interior spaces of the Yukarıköy houses to sustain heavy damage in the form of partial collapse of fireplace and chimney extensions (Figure 7b). In some buildings, chimneys completely collapsed and in others, deformations occurred. There were partial fractures in the upper sections of the external walls in the parts of the fireplace leading up to the chimney. The reasons for this were the irregular bonding systems used in the region, thinning walls and the drying with time of the mud mortar bonding the stone blocks due to extreme heat emitted from the fireplace. In some structures, wooden lintels were used in the upper parts of the load-bearing walls. Because of the thinness of these wooden lintels and the shortness of the section sitting on the walls, the forces of the earthquake running parallel to the walls caused cracks and partial collapse. This type of damage can be seen in Figure 7c. Using larger sizes of stone materials to maintain the continuity and rigidity of the load-bearing walls would have been a more appropriate solution.

In stone masonry buildings, horizontal loads along the plane of the load-bearing external wall generally give way to diagonal shear cracks. In this earthquake, walls with door and window openings, areas on top or between openings commonly sustained these types of shear cracks. Horizontal forces along the wall plane are concentrated in the upper and lower corners of door and window openings and it

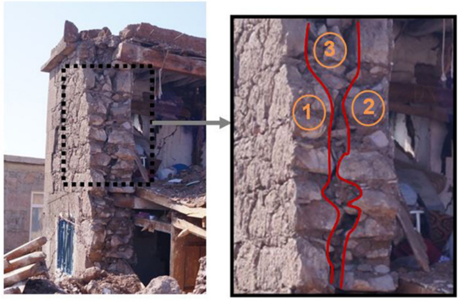


Figure 6. *Size of the stones on the body of the external wall and ruptures in the building system.*

is from here that shear cracks start to appear. These cracks are generally on a diagonal. One of the walls intersecting the diagonal and vertical cracks sustained an impact along the plane and the other perpendicular to the plane. When the vertical crack deepens and fracturing occurs, the connection between the walls falls apart and the independent pieces resulting from the diagonal cracks slide and tumble down due to the horizontal load and the effect of gravity. This type of damage can be seen in Figure 7d.

External walls can become unbalanced due to the disintegration of the bond between the internal and external wall and may consequently fall into an out-of-plane collapse. These types of damage can be seen in the corners of many slender walls. In Figure 7e, the force of the load bearing down perpendicularly on the structure's external wall plane has caused both vertical and diagonal cracks in sections of the lower part of the wall near the joining points and then, a collapse of the wall due to the continuation of tremors. The prevention of this type of damage requires first of all that internal walls are of adequate thickness, that the size of the stone blocks are big enough and of the right formation to ensure rigidity at the joints, that the mud mortar used for bonding is of adequate durability, and that there is a continuity of tie beams at the lower and upper parts of load-bearing walls where they are joined together. Out-of-plane collape could have been prevented if large binding stones had been positioned at vertical regular intervals at the joinings between external and internal walls.The internal wall structures of the houses of Yukarıköy

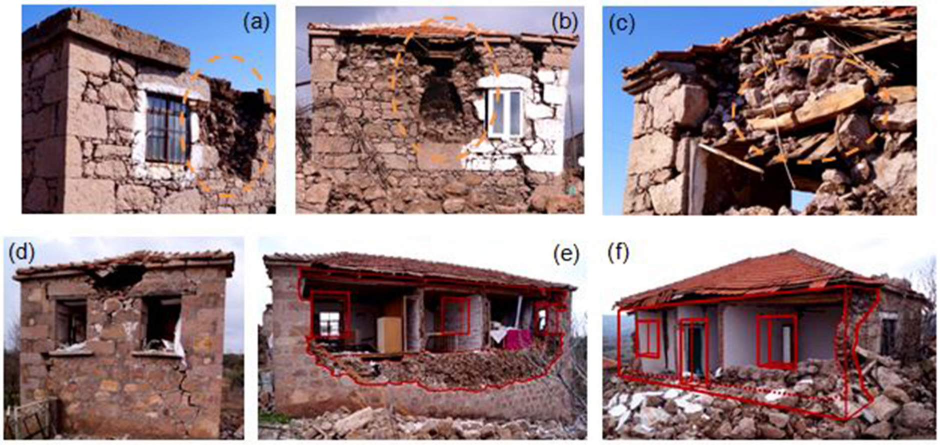


Figure 7. *General damages of body of the external walls: partial collapse and disintegration (a,b,c), diagonal shear crack (d), and out-of-plane collapse (e, f).*

were built from stone, fired clay brick, cement-based briquette blocks and wood. There was no serious damage in the internal walls of these types of buildings. On the other hand, in some buildings, the external walls separated from the internal walls along the plane and collapsed because of the lack of a bonding system that ensured the adequate clamping of internal and external walls (Figure 7f).

The stress on the joining points of the load-bearing external wall increases under the effects of the earthquake. When the corner connections holding up the wall are weak, damage will ensue due to the effect of the different vibrations on walls that are perpendicular to each other. Because of the interaction between these walls, the effects of out-of-plane traction and bending generally cause vertical or diagonal cracks and fractures. In this particular earthquake, the force of the tremors hitting the load-bearing wall plane perpendicularly have generally caused ruptures from bending. In some buildings, disintegration so severe as to cause out-of-plane collapse and ruptures of load-bearing external wall corner joints were observed (Figure 8a, 8b, 8c). The most prominent reason for such disintegration and rupture is the lack of tie beams on the lower and upper parts of load-bearing walls and the absence of an organized pattern of bonding that will ensure the clamping of large blocks of stone. Furthermore, when the size and form of the stone blocks are not reinforced to produce adequate rigidity and bonding is implemented with mud mortar, damage from rupture and disintegration increases. In parts of the load-bearing wall where the roof rafters are perpendicular to the plane, no fracture or out-of-plane collapse was seen because of the decrease in out-of-plane bending moments.

It was observed that some structures in Yukarıköy suffered partial collapse of external walls in the form of pieces that collapse in an upward direction where two walls joined. Figure 8d displays this type of partial collapse. It was seen that this type of damage did not occur in corners sustaining the load impact of the earthquake where large, rectangular stone blocks had been properly bonded together. When window openings are close to corners where walls are joined, the in-plane rigidity of load-bearing walls is reduced. Figure 8e shows a structure where partial collapse has occurred from the impact of the earthquake in the corners where the external walls were joined. Figures 8a, 8c, 8d, 8e and 8f show general damages that were caused by the weak binding at corners . The failure to place binding stones as part of an orderly bonding system at the corner joinings is the main reason for these types of damages. The connections of the roof structure with the load-bearing wall are one of the important factors that impact the earthquake performance of buildings of masonry. The rigidity (i.e. the diaphragm effect) of the floor and roof covering, their integrity and the manner in which they have been bonded to the load-bearing walls

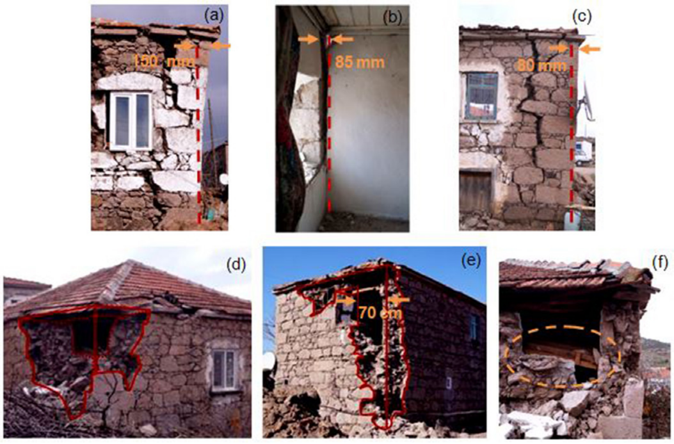


Figure 8. *Vertical displacement of load-bearing external walls (a, b, c) and partial collapse in corner sections (d, e, f).*

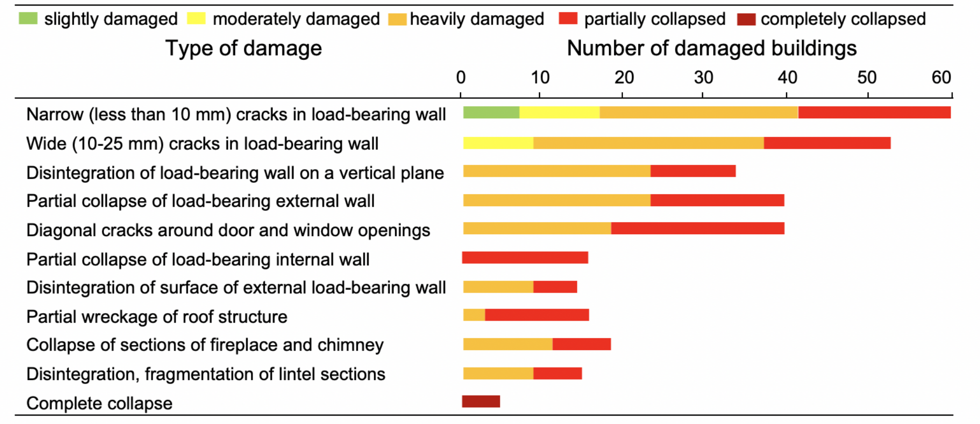
are important elements in preventing walls from separating from each other and disintegrating and in ensuring that the roof does not collapse. If the wooden roof and floor structures had diagonal binding components, neither the roof structure nor the loadbearing wall would have collapsed. In Figure 8f can be seen the damage sustained when ceiling beams of wood directly transfer their load to the load-bearing walls. Here, the lack of connecting beams at the upper sections of the external and internal load-bearing walls, the fact that the wooden beams have been kept shorter than required, the weak connection or the lack of rigidity in the supporting wall are some of the reasons the timber ceiling beams have slipped away from their supports (i.e. unseating) and have partially collapsed. In two-story houses or those where the ground floor level has been elevated, the floor system cannot maintain its rigidity because the floor beams in the intermediate floor systems cannot transfer their load to the walls by means of a tie beam. As a result, the floor construction and the ceiling covering become deformed.

The reason for collapses in the Ayvacık rural houses as a result of the earthquake was the missing technology of masonry bearing wall systems. For example, the absence of large, rectangular binding stones at the corner bindings of loadbearing walls played an important part in bringing about this form of damage. In the same way, on the vertical cross-section, the absence of binding stones binding the internal and external wall facades on the horizontal is a fundamental deficiency. Also, in structures that lacked tie-beams, wooden roof and floor beams were located directly on the loadbearing wall, which constituted another important cause of the damage of collapse. Wooden roof and floor structures that do not exhibit rigid diaphragm behavior should have some stabilizing attributes. Diagonal binding components need to be used in the roof and floor structures to maintain stability. Other causes of this type of damage are the absence of tie beams on the upper and lower sections of the load-bearing walls, the roundness of the stone blocks, the irregularities in the bonding system, and the lack of durability of the bonding material used. Based on the evaluation made according to the data collected from observations, it may be said that there is no need to reinforce the loadbearing walls of the rural houses of Ayvacık that collapsed as a result of the earthquake. Taking into consideration the general evaluation described above in the design and application phases of construction will mitigate the destructive effect of earthquakes to a great degree.

6. Assessment of types of damages and their causes according to the degree of damage

In this section, an assessment of the houses of Yukarıköy was made based on an evaluation of the quantitative data obtained from the distribution of the types and degrees of damage. Seven slightly damaged, nine moderately damaged, thirty heavily damaged, twenty-eight partially collapsed and four completely collapsed buildings, a total of seventy-two houses, were identified in this assessment. At the same time, the prevalence of the structural design and application errors causing the damage have been assessed according to degree of damage. These data, which were produced as a result of the general structural character of Yukarıköy houses, are of importance in ensuring that future reinforcement work and the reconstruction of houses are carried out adequately to maintain durability in the face of possible earth-

***Table 1.** Types of damage caused by the Ayvacık earthquake and distribution of degrees of damage.*



quakes. Table 1 displays quantitative data on the general types of damage and the distribution of these types of damage according to the degree of damage resulting from this earthquakes.

Table 2 demonstrates the prevalence of the structural design and application errors causing the damage according to degree of damage. It can be seen that the cause of thin cracks as the only damage sustained in slightly damaged houses is commonly related to the absence of tie beams and sometimes to weak mortar bonding. The same mistakes can be seen in moderately damaged houses but irregular bonding was rarely observed in these buildings. While there were various levels of structural design and application mistakes made in heavily damaged and partially collapsed houses, mistakes in structural design and application were found in all of the completely collapsed buildings.

7. Conclusions

In the review of the rural houses of Yukarıköy that were most impacted by four earthquakes of magnitudes of 5.2 and 5.3 that hit the district of Ayvacık within six days, it was found that damages sustained were largely destructive. An examination of the quantitative data showed that buildings made of unreinforced masonry with stone walls bonded with mud mortar suffered serious damage from horizontal seismic loads. The failure to use large, rectangular binding stones in the L-corners of the external walls and at the joinings of the internal walls played an important role in the occurrence of destructive damages in the houses. The degree of the damage increased when the stone blocks were of rounded form and in the absence of tie beams on the upper and lower sections of load-bearing walls. Additionally, in structures with no tie beams, the wooden roof and

***Table 2.** Frequency of structural design and application mistakes by degree of damage.*

Causes of damage	Level of frequency according to degree of damage				
	slightly damaged	moderately damaged	heavily damaged	partially collapsed	completely collapsed
Irregular bonding system	-	rare	common	common	common
Weak mortar	rare	rare	common	common	common
Stone block formation	-	-	common	common	common
Stone block size	-	-	occasional	common	common
Absence of beams	common	common	common	common	common
Corners weakly joined	-	-	occasional	occasional	common
Wall-roof structure weakly joined	common	common	common	common	common
Wall-floor structure weakly joined	common	common	common	common	common
External-internal walls weakly joined	-	-	occasional	occasional	common
Different internal wall system	-	-	rare	occasional	common

floor beams were located directly on the loadbearing wall, which enhanced the destructive effect. The absence of diagonal binding components at the roof and floor levels in structures that had tie beams was a fundamental factor that increased the level of damage.

Such structural errors led to the separation of load-bearing walls from each other on a vertical plane under the impact of the earthquakes, caused partial collapse in external walls along the plane, partial disintegration on the face of external walls, long and thick wall cracks on the diagonal, partial collapse of roof and floor structures, and partial destruction of fireplace and chimney sections due to the loss in load-bearing strength. The degree of damage to such houses is classified as "heavily damaged" and "partially or completely collapsed".

The reason for collapses in the Ayvacık rural houses as a result of the earthquake was the missing technology of masonry bearing wall systems . Related to this, it can be said that there is no need for a reinforcement of loadbearing walls. By remedying the structural and application mistakes described above, the destructive effect of the earthquake will be averted.

It will be beneficial from the perspective of protecting cultural heritage to take into consideration assessments made regarding the impact of the Ayvacık earthquakes on the residential structures in the rural areas and the reasons for this impact as well as to minimize the destructive effects of earthquakes on the traditional houses with similar characteristics that are situated in the region.

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