Nat. Hazards Earth Syst. Sci. Discuss., https://doi.org/10.5194/nhess-2017-245
Manuscript under review for journal Nat. Hazards Earth Syst. Sci.
Discussion started: 26 July 2017

Natural Hazards and Earth System Sciences
Discussions
Open Access

Damages during February, 6-24 2017 Çanakkale earthquake swarm

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Abstract. On February 6, 2017 a swarm of earthquakes began at the western end of the Turkey. This has been the first recorded swarm at Çanakkale region since continuous seismic monitoring began in 1970. The number of located earthquakes increased during the next ten days. This paper describes the output of a survey carried out in the earthquake prone towns of Ayvacık, Çanakkale, Turkey, in February 2017 after the earthquakes. Observations collected on site regard traditional buildings at the rural area of Ayvacık. A description of the main structural features and their effects on the most frequently viewed damage modes are related in plane, out of plane behavior of the wall regarding construction practice, connection type etc. It was found that there were no convenient connection details like cavity-ties or sufficient mortar strength resulting in decreased and/or lack of lateral load bearing capacity of the wall.

1 Introduction

Turkey is one earthquake-prone country which is located seismically active regions in ‘Alp–Himalaya Earthquake belt’, and its complex deformation results from the continental collision between African and Eurasian plates (Fig. 1). The major neotectonic elements of the region are the dextral North Anatolian Fault Zone (NAFZ), the Sinistral East Anatolian Fault Zone (EAFZ) and the Aegean–Cyprus Arc which forms a convergent plate boundary between the Afro-Arabian and Anatolian plates (Gürer and Bayrak, 2017). The geological events in the region such as plate motions, seismic activities, crustal deformations are attributed to these major neotectonic entities (Bozkurt, 2001).

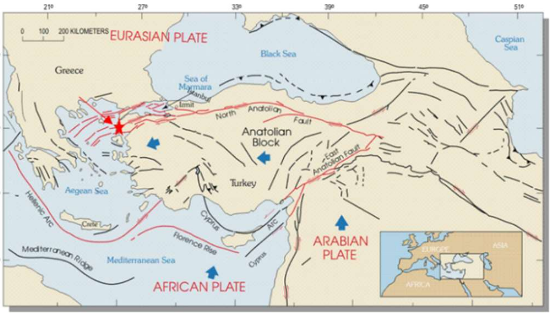

Figure 1 Simplified Tectonic Map of Turkey (USGS, 2005)

On February 6, 2017, a swarm of earthquakes began at the western end of the Turkey at 06:51 at local time. This has been the first recorded swarm at this side of Turkey since continuous seismic monitoring began in 1970's. The number of located earthquakes increased during the next ten days, experienced five times bigger than Mw=5.0 (Table 1). The largest peak from these medium-sized earthquakes are Mw =5.3 February, 6 2017 and Mw=5.3 February, 6 2017 at a depth of 7 and 9.83 km, respectively. The earthquakes and aftershocks taken place on this area between February 6-24, 2017 are shown in Fig. 2. 1930 (M>2.0) earthquakes occurred up to February 24. The propagation of the epicenters of activities and their magnitudes proved the earthquake swarm characteristics. Fig. 3 shows the evidence of the swarm. This graph epicted distribution of both Magnitude vs occurrence date and Magnitude vs cumulative number of the earthquakes via time between 6 to 16 February.

According to active fault map prepared by MTA, these earthquakes are occurred as strike-slip normal fault in the region near the Tuzla segment of Kestanbol fault and Gülpınar fault (Fig. 2). There are five villages which are closer than 5 km to the epicenter of the earthquakes and almost fifteen villages were struck which damaged nearly 1000 houses, and these earthquakes fortunately did not cause any deaths. The closest center of county, where there is almost no critical damage and loss of life, is approximately 15~20 km far from the epicenters of the earthquakes.

Table 1 Parameters of Ayvacık Earthquakes (Afad, 2017)

Date	Local time	Depth (km)	Magnitude ($M_{L,W}$)	Max Acc. (g)
06.02.2017	06:51	14.12	5.3	0.078 (N-S)
06.02.2017	13:58	8.70	5.3	0.103 (N-S)
07.02.2017	05:24	6.24	5.2	0.090 (E-W)
10.02.2017	11:55	7.01	5.0	0.038 (N-S)
12.02.2017	16:48	7.00	5.3	0.089 (E-W)

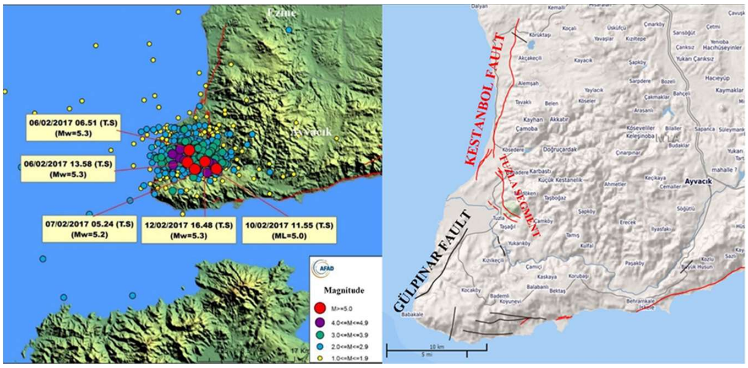

Figure 2 February 6-24 2017 Çanakkale –Ayvacık Earthquakes and aftershocks (Afad, 2017) and Active fault map for Ayvacık, Çanakkale (Emre et al., 2013)

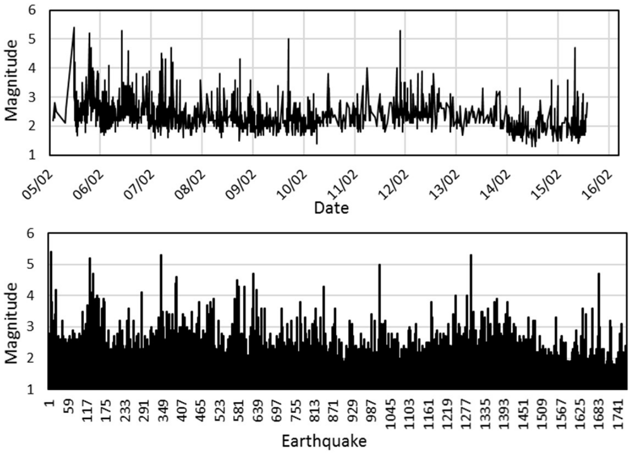

Figure 3 Distribution of the 6-16 February Gülpınar/Ayvacık Earthquakes via date and cumulative number up to related date

In Turkey, there are many different styles of construction type for supporting system. More than 90% of these are reinforced concrete in centers. However traditional rural domestic style of the supporting system is very distinctive resulting from cultural attributes related to the availability of the material and climate condition of the building site. Timber is also one main material preferred building framed mansions and dwellings especially in the Black Sea region of the Turkey and in other regions of the hill/mountain side where timber was abundant. In any case stone continues to be easily found and therefore lack of timber leave people no choice but use more stone in the construction details. However, stone is not convenient material, because of its unit weight and hard to process, in the earthquake prone area. Timber has also an extensive history as a main structural “Hatıl” reinforcing element in rubble stone, brick and adobe houses, the predominant types of houses for ordinary people and especially rural areas (Hughes, 2000) (Fig. 4).

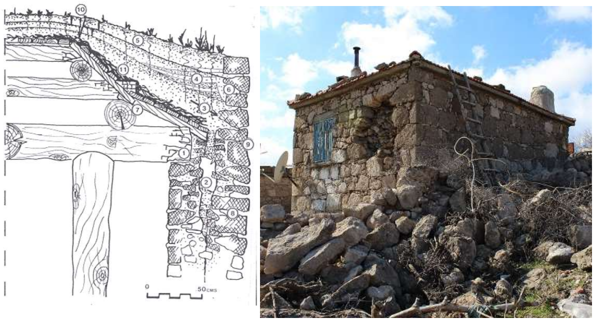

Figure 4 Typical wall construction detail (Hughes, 2000) and typical view of the dwelling from the region

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In the reconnaissance area, observation showed that the construction materials and skills are extremely deficient. Modern materials and techniques are just used in a small part of the observed region. Moreover, cement mortar between stone was not used for almost 50% of the wall. There are a few of building in which reinforced concrete element partly or fully used in the reconnaissance area. Curing of concrete is still not practiced as an integral part of the concreting process. The concrete blocks are of poor quality because of the poor quality of the concrete, a lack of compaction and very little or no curing. The existing building types in the area are shown in Fig. 5.

A field reconnaissance was carried out by the authors immediately after the earthquakes on 12, February, and the observations were reported in the present paper. The authors also experienced 12 February Mw=5.3 earthquake during their observations. Objective of the field reconnaissance was to record the causes of the damage patterns observed in the buildings, mainly in the rural areas affected from the earthquakes swarm. The paper discusses the seismological aspects of the earthquakes, describes the classifications of buildings in the area and elaborates on the performance of various building types during the earthquakes.

Figure 5 Existing building types in reconnaissance area: a) hatıl dwelling b) stone and brick in cement mortar, c) engineered RC building d) hatıl building with heavy roof, e) historical masonry with cut stone, f) cut stone without mortar, g) stone without mortar, h), i) stone in cement mortar with reinforced concrete.

2 Ground motions and Response spectra

An instrument situated in a low-rise appurtenant building adjacent to the local office of the Forestry Operation Directorate of Çanakkale Ayvacık recorded the shock as being 15~25 km away from the hypocenters. The three accelerations recorded by this instrument are given in Fig. 6. As seen from this figure, the peak ground accelerations (amax) are 70~110 mG (cm/s2) in the North-South direction, 70~90 mG in the East–West direction, and 20~30 mG in the vertical direction for the shocks bigger than Mw=5. According to Turkish Earthquake Code (TEC 2007), the seismic zone of the city of Çanakkale is classified as 1, where the probability of exceeding an effective peak ground acceleration of 0.4g is 10 percent in 50 years or the return period is 475 years. As can be seen in Fig. 6, the peak value of acceleration occurred 110 cm/s2 in the N–S component maximally. It should be noted that peak ground acceleration didn't exceed the seismic hazard defined as to be 0.4g for the area in the seismic zone map of Turkey.

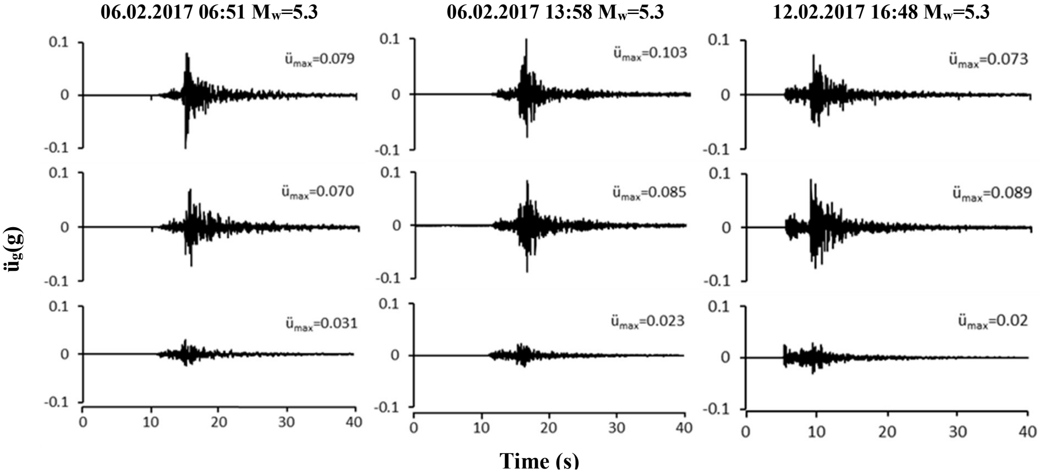
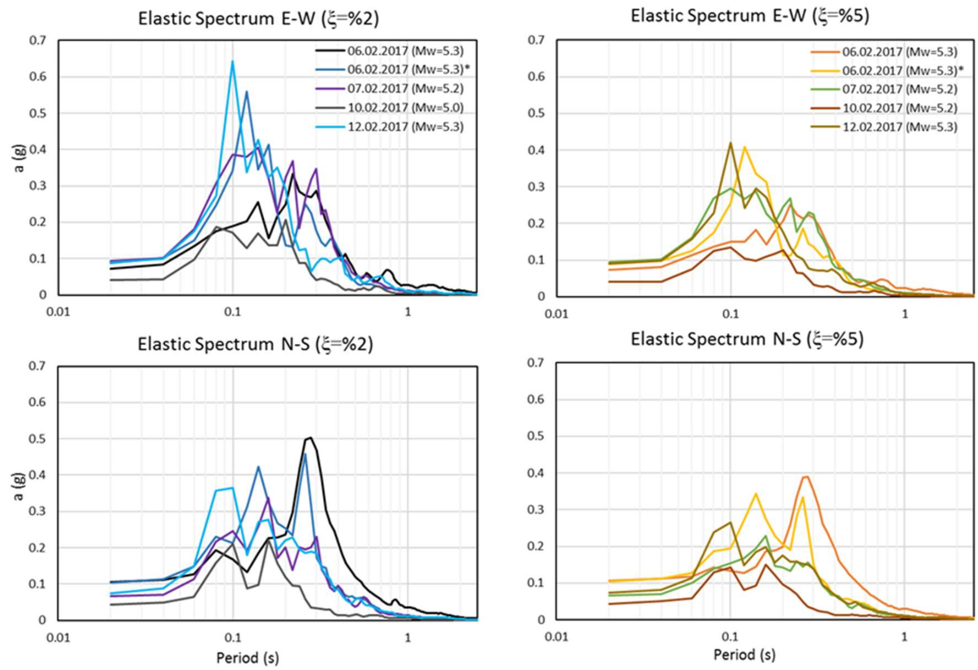


Figure 6 Three components of ground acceleration (Mw> 5.2) of February 6-24, 2017 Çanakkale Earthquakes

Response spectra with damping ratio of 2 and 5% for horizontal components are computed and given in Fig. 7. This figure shows that the earthquake shaking would be most effective on structures having a natural period of approximately up to 0.4 s. The strong ground motion records, taken from Forestry Operation Directorate enabled us to determine the attenuation of the ground accelerations. The peak ground acceleration from the five earthquakes was approximately 0.105 g at the station, which is 24 km from the epicenter. Similarly, the peak ground acceleration were 0.03 g, 0.009 g and 0.004 g at Ezine, Bozcaada and Bayramic stations, which are 31, 33, and 48 km far from the epicenter, respectively



*This earthquake is the second earthquake occurred in the same day having a magnitude of 5.3

Figure 7 Elastic acceleration response spectrums for N–S and E–W components of (Mw> 5) of February 6-24, 2017 Çanakkale Earthquakes

The peak ground acceleration (PGA) values of Ayvacık records are indicated on prepared attenuation curve by Gülkan and Kalkan (2002) for M = 5.5 as shown in Fig. 8. The correlation of the observed data with the proposed empirical expression is very satisfactory. It should be noted that because the observed towns are approximately within 3-5 km distance to the epicenter of the earthquakes, the attenuation relation point out the damaged and collapsed building might have experienced 0.2 g and 0.25 g PGA for rock and soil site condition respectively during the earthquakes. When elastic response spectra calculated by using the Earthquakes and attenuation would be considered, the results show that the maximum acceleration exciting the buildings might reach maximally 0.25g in the reconnaissance area. On the other hand, the damping ratio maximally get 5% for such masonry and adobe structures according to Turkish Earthquake Code, however, offered the design acceleration as 0.5g in this region for the masonry buildings. Even this comparison is the best evidence that damaged or collapsed building did not get any engineering service or were not built considering any code rule.

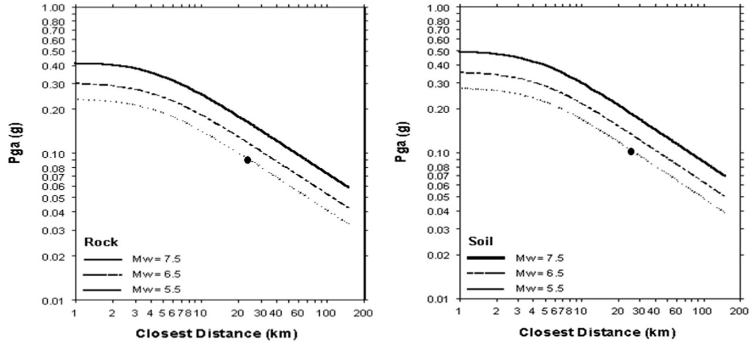


Figure 8 Curves of peak acceleration versus distance for magnitude 5.5, 6.5 and 7.5 earthquakes at rock and soft soil sites (Gülkan and Kalkan, 2002)

3 Damage profile

Since, the energy release was relatively very small comparing to the earthquakes occurred on NAFZ or on the other most active zone EAFZ of Turkey, no RC structures collapsed in the area other than the poorly constructed stone masonry dwelling in rural area. In thirteen towns alone, where there were about 1000 damaged or collapsed buildings, more than 40~50% of the mansion or dwelling either collapsed or were heavily damaged. According to initial official estimates, within the disaster zone, a total of 562 buildings were heavily damaged, 392 buildings suffered medium or minor repairable damage. Single or a few storey non engineered heavy masonry buildings with very poor details, however, along the sloping hills to the west of Gülpınar-Ayvacık, practically survived the earthquake without significant damage. It should be also noted that Gülpınar is relatively close to the epicenter of the earthquake than other town such as Taşağıl, Yukarıköy and Çamköy where dwellings were suffered very high damages. Gülpınar is also historical center in this area and has the cultural heritages, so the differences in terms of the cultural accumulation and development level between Gülpınar and the other towns affect the quality of the construction. Thus, the structural damage was concentrated mainly in the towns which have relatively very low economical level and where there are not any engineered buildings observed by the author.

Failure mechanisms observed during the 2017 Çanakkale Earthquakes were also observed in other recent moderate earthquakes in Bala (ML=5.5), Doğubeyazıt (ML=5.1) and Dinar (ML=5.9) etc. (Tezcan, 1996; Bayraktar et al., 2007; Adanur, 2008; Ural et al., 2012). Adanur (2010) showed that in 20 and 27 December 2007 Bala (Ankara) earthquakes, masonry buildings were built in three types in the affected area: (1) stone masonry buildings with walls made of natural shaped stones, (2) stone masonry buildings with walls made of cut stones, and (3) mixed masonry buildings with walls made of masonry materials like stones and mud bricks or stones and bricks or stones and briquette. From all a total of 945 buildings were heavily damaged or collapsed in Bala. Bayraktar et al. reported that 1000 building affected from the earthquake in Doğubeyazıt. Similar to the above-mentioned studies, so far experiences from such moderate earthquakes in rural area of Turkey have shown that even low-moderate earthquakes may cause significant damages on Non-reinforced masonry structures (Fig. 9). This type of masonry is among the most vulnerable type of buildings during an earthquake. Even under moderate lateral force such a masonry structure is damaged or collapsed, due to lock of shear strength, improper interlocking mechanism and/or poor bond between stone-stone or stone-mortar. In this case shear failure is inevitable in plane forming of diagonal cracks or similar cracks wherever is suitable to damage through the wall because of defects due to workmanship. Furthermore, when the wall did not design considering any engineered rule, the catastrophic and rapid collapses occur in out-of-plane flexure mode. In addition to the general failure mode above mentioned, the technical reasons for damages and collapse observed reconnaissance may be summarized in detail as follows.

Figure 9 Totally collapsed examples from Ayvacık, Çanakkale 2017 earthquakes swarm

- Inadequate interlocking among the stone

In the rural area of Turkey, the construction of dwelling is by the owner –occupier with aid of craftsmen who live in the locality but who are not full-time builders. These builders are usually taught their trade as a result of apprenticeship. Consequently, they have their own tools without any scientific rule and in the site the construction technique is still alive and building technique is so similar among the dwelling. For example, during the observation it is apparently shown that even thick mortar or mud was not used as binding agent between stone or masonry unit for almost all damaged dwellings. The Fig. 10 is a conspicuous example that heavy damages during the earthquakes were taken place for lack of mortar between stones. At the end of several moderate earthquakes this masonry dwelling became unstable.

Figure 10 An example of damaged dwelling due to inadequate interlocking

Another damage type observed in the region is outward bulking of wall which caused by interlocking deficiency. The reason of this deficiency is vertical gap between stones creating wall thickness as shown in Fig. 11. In order to prevent this damage, horizontal elements such as hatıl or key stone, which provide integrity to masonry wall, can be used in specific intervals vertically. The key stones or hatıls can provide limited resistance to lateral seismic loads and thus probably prevent the out-of-plan failure on some part of masonry walls.

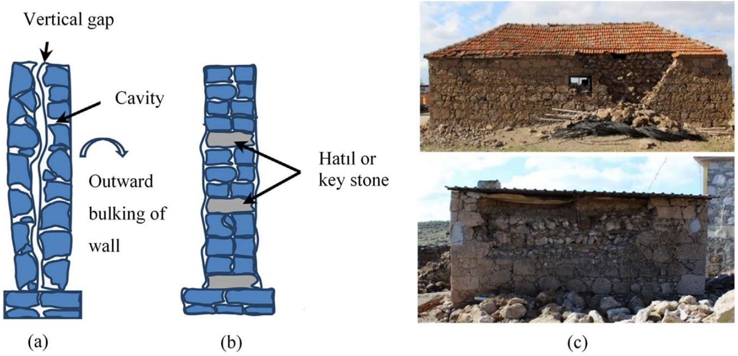


Figure 11 Schematics of a conventional wall section without through stone, b wall section with through stones (Sharma, 2016) c observed damages in the region.

An additional interlocking damage type is observed at the intersection of perpendicular walls (Fig. 12). One of the walls acts out of plane while other remains very stiff in plane resulting in inevitable cracks. Damages in this type can either result in gaps developing between the in-plane and the out of plane wall or vertical cracks may occur in the out of plane wall (Tolles et al. 1996). Further phase of this damage may result in out of plane failure of gable-end wall. To avoid intersection damage, interlocking between perpendicular walls in the corners should be appropriately designed against lateral earthquake forces.

Figure 12 Observed damages at intersection of perpendicular walls

- Irregular designed wall with cavity

The design process of the masonry buildings needs to regularity more than other supporting system, because lateral load resisting system must have continuity to meet shear force stemming from earthquake. In the rural area, however, traditional fireplace was used in the buildings and it is built within the wall by decreasing the wall thickness or curving the wall outward. In such a case irretrievable damage is occurred on the wall because of the decreasing the shear resistance (Fig. 13). This damage type was observed for different masonry structures in the site. For example, it can be seen from Fig. 13 that there were different examples like cut stone masonry, stone with plaster and stone without mortar. The common damage type is most likely stemming from the lack of skill of craftsman or traditional habits.

Figure 13 Examples of out of plane collapse due to wall cavity

- Heavy Earth Roof

Another important reason that causes damage is the roof made from a thick and heavy layer of mud spread upon wooden logs (Fig. 14). This technique is widely used in some part of Anatolian region where timber is increasingly scarce. These heavy earth roofs are generally made hardening spreading soil with a cylindrical stone. To make the earth roof more durable against water leakage need to be thickened more and more over the years. Consequently, heavier earth roof cause bigger shear force during the earthquake. In general, the roof either supported by the beam and indirectly by the wall or inner structures beams and columns were round or sub-round in section, the trunk without its bark. This made connections and good bearing surfaces between them virtually impossible. Such beams were prone to roll off the other during the earthquake induced motions. Also, the round beam-ends point loaded (to an excessive degree) the supporting walls beneath and then collapse of the earth roof or wall is inevitable.

Figure 14 Examples of heavy earth wall collapse

- insufficient wall rigidities

In many cases, distinctive diagonal or inclined cracks have been observed in load-bearing window piers or walls with low width-to-height ratios as a result of inadequate shear resistance (Tomazevic, 1999). While bending and shear from moderate earthquake can be easily resisted by reinforced-masonry with lateral and horizontal elements such as RC or timber (Fig. 15), the dwelling made by stone in no mortar cannot resist them. This construction defect is causing in-plane failures by means of excessive shear force or bending or out of plane failure by bending depending on the aspect ratio of the unreinforced masonry elements.

Figure 15 Examples of undamaged dwellings

Many weak masonry walls without mortar had diagonal or inclined shear cracking as a result of cyclic shear forces applied during the earthquakes (Fig. 16). But this diagonal shear cracking does not necessarily lead to total collapse in general. However, collapse may be inevitable if the triangular wall blocks on each side of a full diagonal crack become unstable by substantially losing their interlock or friction resistance along the cracks (Fig. 17). Similar failures were previously reported around the world (Ural et al., 2012; Klingner, 2006).

Figure 16 Examples of diagonal shear cracking

Figure 17 Out of plane failures depending on improper wall thickness and/or height-length ratio

There were no industrial buildings within Ayvacık and no damage was observed along the highway or at bridges. There were not any reported landslides, rack fall.

4 Conclusions and Recommendations

The aim of this paper is to evaluate the characteristics of earthquakes and to investigate the damage and collapse mechanisms observed in buildings during a rarely occurred event called earthquake swarm struck Ayvacık, Turkey, between 06 - 24 February 2017. This earthquake swarm includes more than 1500 earthquakes with some moderate earthquakes (Mw > 5.0). Additionally, the properties of these earthquakes regarding civil engineering such as peak ground acceleration, response spectrum are specified. Although determined elastic spectrum remains under design spectrum of TEC (2007), significant damages and failures of many masonry structures were observed in reconnaissance area. The reason of these damages and failures observed in survey can be explained as: (1) damaged buildings are close to epicenter of earthquakes, (2) influence of pre-existing cracks on the performance of buildings due to many earthquakes occurred in a short period of time, (3) deficiency of construction process including poor workmanship and material quality, construction without any scientific rule or code and lack of tie or connection between structural elements.

In conclusion, it is suggested by the authors that the construction practice, commonly used in the affected region and caused damage and failure of buildings, should be avoided and if this kind of structures are available in the region, required precautions should be taken against probable earthquakes.

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