<u>**Response to Dr. Molinari;**</u>

We would like thank to the editor for the time spent in reviewing our article and her valuable comments. Authors tried to present a revised version of the paper, in which most part of the editor's comments were attended and with considerable improvements on the written text. Some revisions are presented in the following pages along with explanations. We have tried our best to accommodate all scholarly comments provided by the reviewer and clarify the ambiguities. We also scrutinized the whole paper and attached new sections to the text to overcome the arisen unclearness through the paper. But It is worth noting that in civil engineering point of view, authors built the goal of the paper to help the engineers to show damages due to local construction types in moderate seismic events and to better understand damages observed in the site. Anyone can easily find similar articles in the literature which give similar results for earthquakes but every observation includes unique damages belonging the area due to the earthquakes and/or special features of the region. In this context we hope the revised paper satisfy the standards of your board.

1. *The first one is the survey. I think that the way in which you conducted the research (how many buildings? In which area? How they were chosen? Why? How many persons involved? Which tools/instruments you implemented? How long does it take?) as well as its objectives (Which are the parameters, aspects, evidences you collected? Why?) must be fully described, also in order to allow other research to repeat the experience and to compare their results with yours. Maps suggested by the first review can support the discussion.*

<u>**Authors Reply:**</u>

*a) How many buildings?*

Number of buildings according to villages are given Figure 10. Moreover, total number of buildings are added to the text as below with updated numbers.

"According to the data obtained from Çanakkale Provincial Directorates of Environment and Urbanization, in twenty-nine villages alone, there were about 2705 damaged or collapsed buildings out of 5790 structures while 3083 structures did not suffer any damage. According to official estimates, within the affected area, a total of 1470 (25%) structures (including buildings, houses, barns, offices, stores and haylofts) were heavily damaged or collapsed, and 1235 (22%) structures suffered medium or minor repairable damage. Moreover, a total of 3083 (53%) structures did not suffer any damage."

*b) In which area?*

The location of the research area is shown with a red star on the tectonic map of Turkey in Figure 5. In addition, locations of investigated 29 villages with earthquakes are given in detail in Figure 9. The Latitudes and longitudes of the earthquakes are given in Table 1 (indicating the area in which the research is conducted).

The authors think that there are enough information explaining the area of the research. However, if the editor has a better or alternative choice, the authors will try to evaluate and improve the value of the paper.

*c) How they were chosen?*

The buildings in selected villages close to the earthquake epicenter are mostly affected from the earthquake swarm. Since almost 6000 buildings were available in the 29 villages, the authors received support from Çanakkale Provincial Directorates of Environment and Urbanization for the official numbers according to damage level (heavily, collapsed etc.). due to this information reconnaissance team including all authors focused on the damaged area. In civil engineering point of view, it is the most important point for the authors that why damages occurred during a moderate earthquake. Observation on the damages and their reasons were tried to express in the manuscript

*d) How many persons involved? How long does it take?*
These questions are answered by revising the first sentence of the last paragraph of introduction as below:

"A field reconnaissance was carried out by four authors immediately after the earthquakes on February 12-17, for a period of five days and the observations were reported in the present paper."

*e) Which tools/instruments you implemented?*

The aim in reconnaissance researches with viewpoint of civil engineering is to observe damage profile and damage level of structural elements of building as well as their causes rather than non-structural elements. For this reason, simple tools are generally used in this type of researches such as laser meter, meter or plumb. The authors do not find necessary to express these simple tools.

*f) Which are the parameters, aspects, evidences you collected? Why?*

One of the objectives of the reconnaissance paper is to investigate and evaluate the damage patterns of buildings and its causes. This is expressed at the last paragraph of the introduction as:

"The objective of field reconnaissance was to record the causes of the damage patterns observed in the buildings, mainly in the rural areas affected by the earthquake swarm."

Another objective is to evaluate the relationship between response spectra and structural damage. This is stated in the 3$^{rd}$ chapter of the paper.

Additionally, damage distribution of structures (Figure 12-14) in terms of villages and structure types as pie charts (Figure 15) according to damage levels are created and inserted to the text in chapter 4.1.

*g) Also in order to allow other research to repeat the experience and to compare their results with yours. Maps suggested by the first review can support the discussion.*

First of all, the authors try to do their best in order to fulfill the editor's advice to improve the quality of the paper. However, this type of papers generally includes damage types and its levels after earthquake in reconnaissance area as well as earthquake characteristics. There are several similar studies in literature such as Sharma et al. (2016), Adanur (2010) and Xiong et al. (2015). Therefore, the scope of the paper contains similar topics to above studies. Maps suggested by the first referee have been already added and explained in chapter 4.1.

**2.** *The second one concerns results. How can I use collected evidences on damage and its cause? E.g. (1) for calibrating new damage models or validate existing one, in order to improve our risk knowledge of the area? If this is the case, why you did not analyse the relation between hazard and vulnerability? (2) to identify the buildings which are most at risks? How? according to which criteria? (3) to suggest mitigation strategies, e.g. retrofitting, better spatial planning, etc.; what results tell us about this? (4) others?*

**Authors Reply:**

**a)** *(1) for calibrating new damage models or validate existing one, in order to improve our risk knowledge of the area? If this is the case, why you did not analyse the relation between hazard and vulnerability?*

It is not aimed in this study either calibrating new damage model or validate existing one. This is not in the field of the authors expertise. But if anyone want to study in this object we could support them for any aspects.

**b)** *(2) to identify the buildings which are most at risks? How? according to which criteria?*

A comprehensive explanation is conducted and added to the paper as below (Figure 15):

"Distribution maps mentioned above are created for all structures regardless of the structure types. However, evaluation of damage levels according to structure types may introduce a new perspective in interpreting the damages. Besides, such a parametric study may be a guide in order not to repeat similar mistakes when reconstructing structures with a high heavily damaged/collapsed ratio according to structure types. Damage ratios according to six structure types are generated in Figure 15 with the support of Çanakkale Provincial Directorates of Environment and Urbanization. As can be seen from the figure, the construction practices applied on Haylofts and Barns should be substantially revised in order to minimize damages from a potential similar earthquake. On the other hand, the techniques used on structures having a heavily damaged ratio of approximately 25%, such as stores, houses and buildings may be reviewed and enhanced according to technical deficiencies mentioned in the next section. It can be seen that office structures experienced relatively less damage compared to other structure types. Thus, it can be said that construction of office structures were performed more in line with the conditions required by TEC' 2007."

**c)** *(3) to suggest mitigation strategies, e.g. retrofitting, better spatial planning, etc.; what results tell us about this?*

Most of damaged structures in the affected area are constructed with poor workmanship and material quality, construction without any scientific rule or code and lack of tie or connection

between structural elements. Hence, retrofitting these damaged structures can not be logical and economic according to authors observations. Furthermore, one or more retrofitting techniques may require for each damage type mentioned in 4th section of the discussion paper. For this reason, authors consider that retrofitting technique should be investigated extensively rather than suggesting these techniques in conclusion. And this case (adding retrofitting techniques) will cause further extension of the paper and is beyond the scope of the paper.

> *"I think that, at present, results (or better evidences) are simply discussed in a narrative form without any critical analysis of them… which can be the really added value of the research. But, above all, what results tell us which is novel with respect to the state of the art?"*

- As we discussed in the manuscript and responses given here, the structure type used in the site is not common types neither for Turkey nor for the other earthquake zones all over the world. So every observed damages i.e failure examples due to improper interlocking mechanism and/or lack of bonding between stone-stone or stone-mortar give us special failure type for such a regional construction. It is almost not possible to see such connection details in earthquake prone-areas. Besides other a lot of information given in the manuscript only this information will attract readers' attention.

> *"At last, a re-organisation of the contents and a revision by a native speaker are required. The poor English and the fragmented organisation of the manuscript do not help the full comprehension of its main contents."*

- For re-organisation of the paper, introduction is divided into two different sections in earlier revision, as suggested by Dr. Kundak. For a full comprehension of the main contents of the paper, as suggested by the Editor, 4th section of the paper is divided into two separate subsections.

The manuscript is scrutinized and rewritten by native speaker according to the comments.

**References**

Adanur, S. (2010), "Performance of masonry buildings during the 20 and 27 December 2007 Bala (Ankara) earthquakes in Turkey", Natural Hazards and Earth System Sciences, 10(12), 2547. doi: 10.5194/nhess-10-2547-2010

Sharma, K., Deng, L. and Noguez, C.C. (2016), "Review article: Field investigation on the performance of building structures during the April 25, 2015, Gorkha earthquake in Nepal", Engineering Structures, 121,61-74. doi:10.1016/j.engstruct.2016.04.043

Xiong, F., Xie, L., Ge, Q., Pan, Y., & Cheung, M. (2015). Reconnaissance report on buildings damaged during the Lushan earthquake, April 20, 2013. Natural Hazards, 76(1), 635-650.

**Best regards...**

# 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~~ were made on site regarding

10  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~~ were made ~~related~~ according to ~~in~~ plane, out of plane behaviour 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

15  On February 6, 2017, a swarm of earthquakes began at the western end of ~~the~~ Turkey at 06:51 local time. This has been the first recorded swarm ~~at~~ in this ~~side~~ region of Turkey since continuous seismic monitoring began in 1970. The number of located earthquakes increased during the next ten days~~,~~ ~~experienced five times~~ and earthquakes bigger than Mw=5.0 were experienced five times (Table 1). These data ~~are~~ were taken from DEMP (Disaster and Emergency Management Presidency). The largest peaks from these medium-sized earthquakes ~~are~~ were occurred twice (Mw =5.3) at different local times ~~Mw =5.3~~

20  ~~on~~ February, 6 2017 ~~, and Mw=5.3 on February, 6 2017~~ at a depth of 7 and 9.83 km, respectively (Table 1). The earthquakes and aftershocks ~~taken~~ that took place ~~on~~ in this area between February 6 ~~and~~ –24, 2017 are shown in Fig. 1a. A total of 1930 earthquakes (M>2.0) occurred ~~up to~~ until February 24. The propagation of the ~~epicenters~~ epicentres of activities and their magnitudes proved the earthquake swarm characteristics. Fig. 2 shows the evidence of the swarm. This graph ~~epicted~~ depicts distribution of both Magnitude ~~vs~~ vs. occurrence date and Magnitude ~~vs~~ vs. cumulative number of ~~the~~ earthquakes via time

25  between February 6 ~~to 16 February~~ and 16.

According to the active fault map prepared by MRE (General Directorate of Mineral Research and Exploration), these earthquakes ~~are~~ occurred as strike-slip normal fault in the region near the Tuzla segment of Kestanbol fault and Gülpınar fault (Fig. 1b). There ~~are~~ were five villages which ~~are~~ were closer than 5 km to the ~~epicenter~~ epicentre of the earthquakes. ~~and a~~ Around 30 villages were struck by the earthquakes, which damaged nearly 2600 houses, and ~~these earthquakes~~ fortunately

did not cause any deathsthere were no casualties. The closest centercounty centre of county, where there is almost no critical damage and loss of life, is approximately 15~20 km far from the epicentersepicentres of the earthquakes.

Table 1. Parameters of Ayvacık Earthquakes (DEMP, 2017)

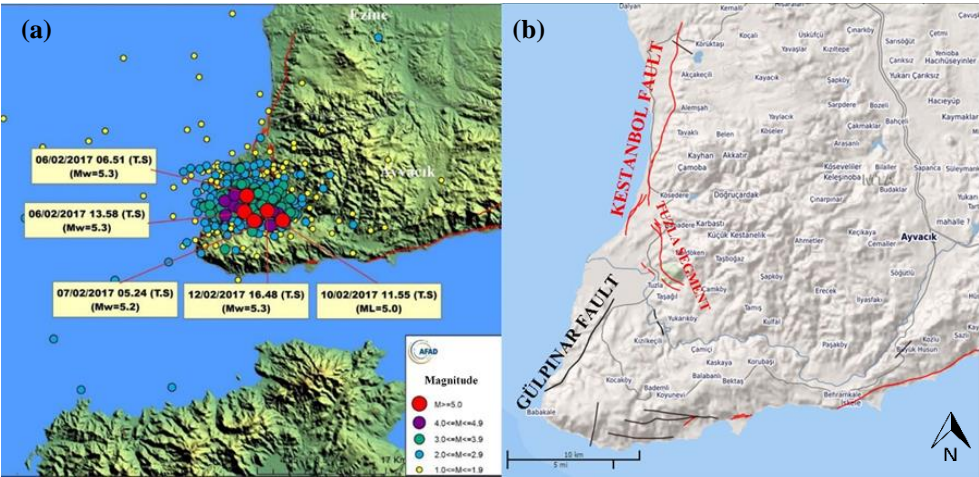| Date | Local time | Latitude | Longitude | Depth (km) | Magnitude ($M_{L,w}$) | Max Acc.-PGA (g) |
|---|---|---|---|---|---|---|
| 06.02.2017 | 06:51 | 39.5495 | 26.137 | 14.12 | 5.3 | 0.078 (N-S) |
| 06.02.2017 | 13:58 | 39.5303 | 26.1351 | 8.70 | 5.3 | 0.103 (N-S) |
| 07.02.2017 | 05:24 | 39.5205 | 26.157 | 6.24 | 5.2 | 0.090 (E-W) |
| 10.02.2017 | 11:55 | 39.5236 | 26.1946 | 7.01 | 5.0 | 0.038 (N-S) |
| 12.02.2017 | 16:48 | 39.5336 | 26.17 | 7.00 | 5.3 | 0.089 (E-W) |

5



**Figure 1: (a) February 6-24 2017 Çanakkale –Ayvacık Earthquakes and aftershocks (DEMP, 2017) (b) Active fault map for Ayvacık, Çanakkale (Emre et al., 2013)**
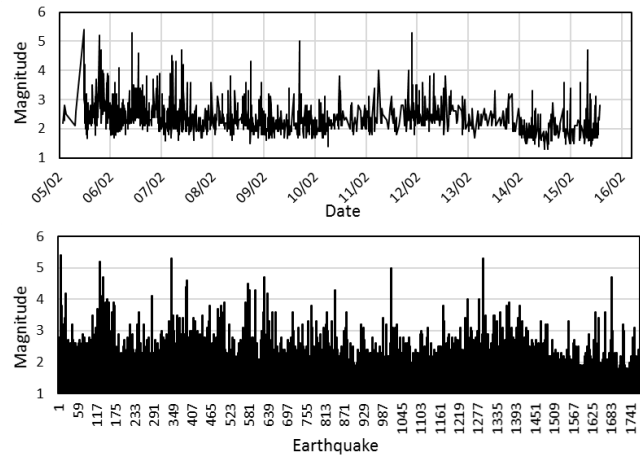
**Figure 2: Distribution of the 6-16 February Gülpınar/Ayvacık Earthquakes via date and cumulative number up to related date**

In Turkey, there are many different ~~styles of construction type~~construction styles for supporting system~~s~~. More than 90% of these are reinforced concrete in city ~~centers~~centres. However, traditional rural domestic style ~~of the~~ supporting system~~s~~ ~~is~~ are

5   very ~~distinctive~~distinctive; resulting from cultural attributes related to the availability of ~~the~~ material and climate condition~~s~~ of the building site. Timber is also one of the main material~~s~~ preferred in building framed mansions and dwellings, especially in the Black Sea region of Turkey and in other ~~regions of the~~ hill/mountain side regions where timber is abundant. In any case, stone ~~continues to~~is a material that can be easily found, and ~~therefore~~ lack of timber leave~~s~~ people no choice but to use more stone in ~~the~~ construction details. However, stone is not a convenient material in earthquake prone areas, because of its

10  unit weight and ~~hard to process, in the earthquake prone area~~being difficult to process. Timber ~~has~~ also has 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 in rural areas (Hughes, 2000) (Fig. 3).



15  **Figure 3: Typical wall construction detail (Hughes, 2000) and typical view of ~~the~~ a dwelling from the region**

In the reconnaissance area, observations showed that the construction materials and skills ~~are~~ were extremely deficient. Modern materials and techniques ~~are~~ were ~~just~~ only used in a small ~~part~~portion of the observed region. Moreover, cement mortar between stone~~s~~ was not used ~~for~~in almost 50% of the wall~~s~~. There ~~are~~ were a few ~~of~~ buildings in which reinforced concrete element~~s~~ were partly or fully used ~~in the reconnaissance area~~. Curing of concrete is still not practiced as an integral

20  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. 4.

A field reconnaissance was carried out by four ~~the~~ authors immediately after the earthquakes on February 12-17, ~~February for a period of five days,~~ and the observations were reported in the present paper. The authors also experienced ~~12 February~~ the Mw=5.3 earthquake on 12 February during their observations. The ~~Objective~~objective of ~~the~~ field reconnaissance was to

3

record the causes of the damage patterns observed in the buildings, mainly in the rural areas affected ~~from~~ by the earthquake~~s~~ 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 4: 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 Seismicity of the Region

Turkey is an earthquake-prone country which is located on seismically active regions in the 'Alpine–Himalayan Earthquake belt', and its complex deformation ~~results from~~is a result of the continental collision between African and Eurasian plates (Fig. 5a). 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~~and crustal deformations are attributed to these major neotectonic entities (Bozkurt, 2001).

In this study, the region of north-west Anatolia has been investigated from both land and sea. This region ~~investigated region, north-west Anatolia, as both land and sea,~~ is one of the most important active seismic and deformation regions between Eurasian and African tectonic plates. The region is affected ~~from~~ by both the strike-slip tectonic regime, which is a general characteristic of NAFZ, and the extensional regime of west Anatolian block. The most effective earthquake within

4

the instrumental period (after 1900) around the region ~~are~~ are the Aegean Sea earthquake (M=7.2) that occurred in 1981, Ayvacık-Çanakkale earthquake (M=7.0) in 1919, and Edremit gulf earthquake (M=6.8) in 1944 (KOERI, 2017) as shown in Figure 5b.
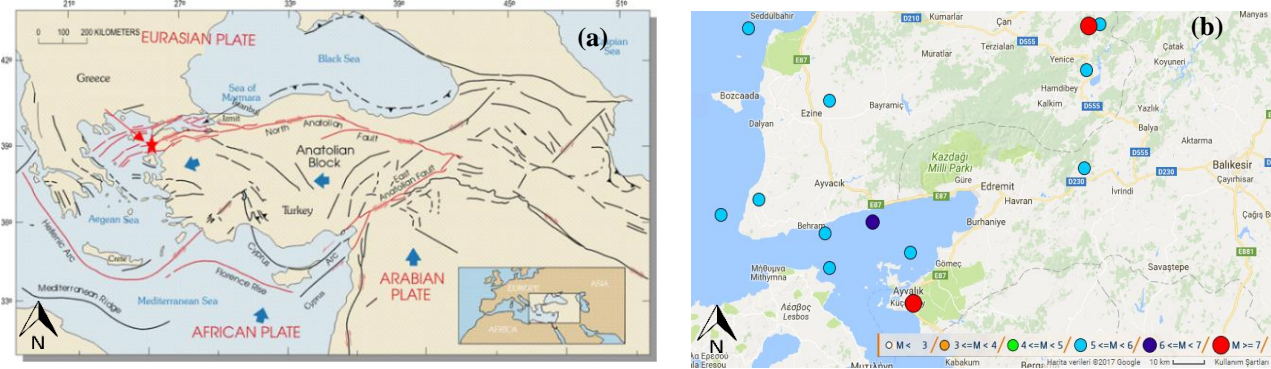


**Figure 5: Simplified Tectonic Map of Turkey (USGS, 2005)**

## 3 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~~ in this figure, the peak ground accelerations (amax) are 70~110 mG (cm/s$^2$) 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 $M_w$=5. According to earthquake zoning map of Turkey, prepared by General Directorate of Disaster Affairs in 1996, 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 (TEC 2007). As can be seen in Fig. 6, the peak value of acceleration was maximal in the N–S component and occurred as 110 cm/s$^2$ ~~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~~ this area in the seismic zone map of Turkey.

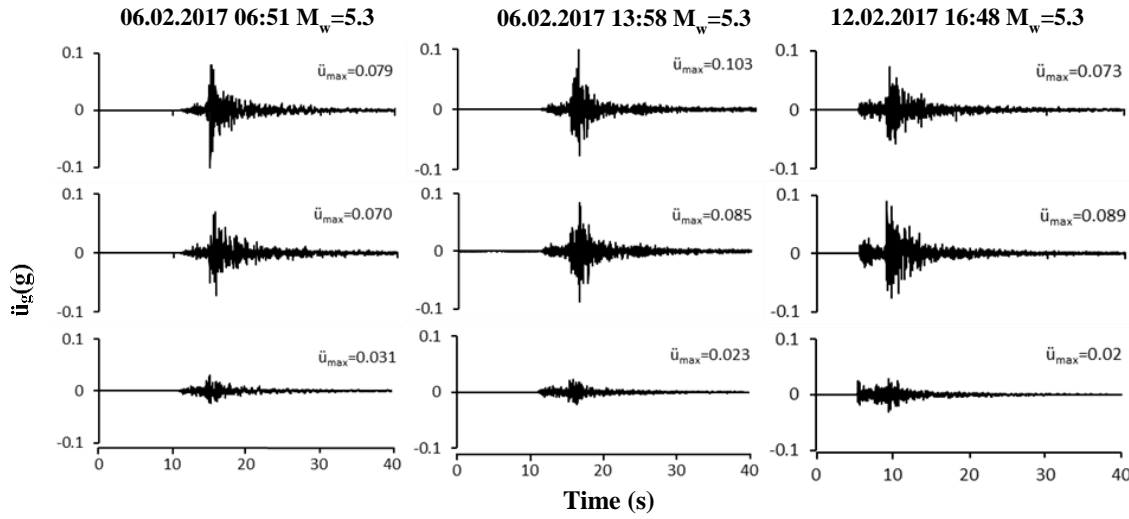**06.02.2017 06:51 M$_w$=5.3**  **06.02.2017 13:58 M$_w$=5.3**  **12.02.2017 16:48 M$_w$=5.3**

Time (s)

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

Response spectra with a 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 away from the epicenterepicentre. 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 away from the epicenterepicentre, respectively
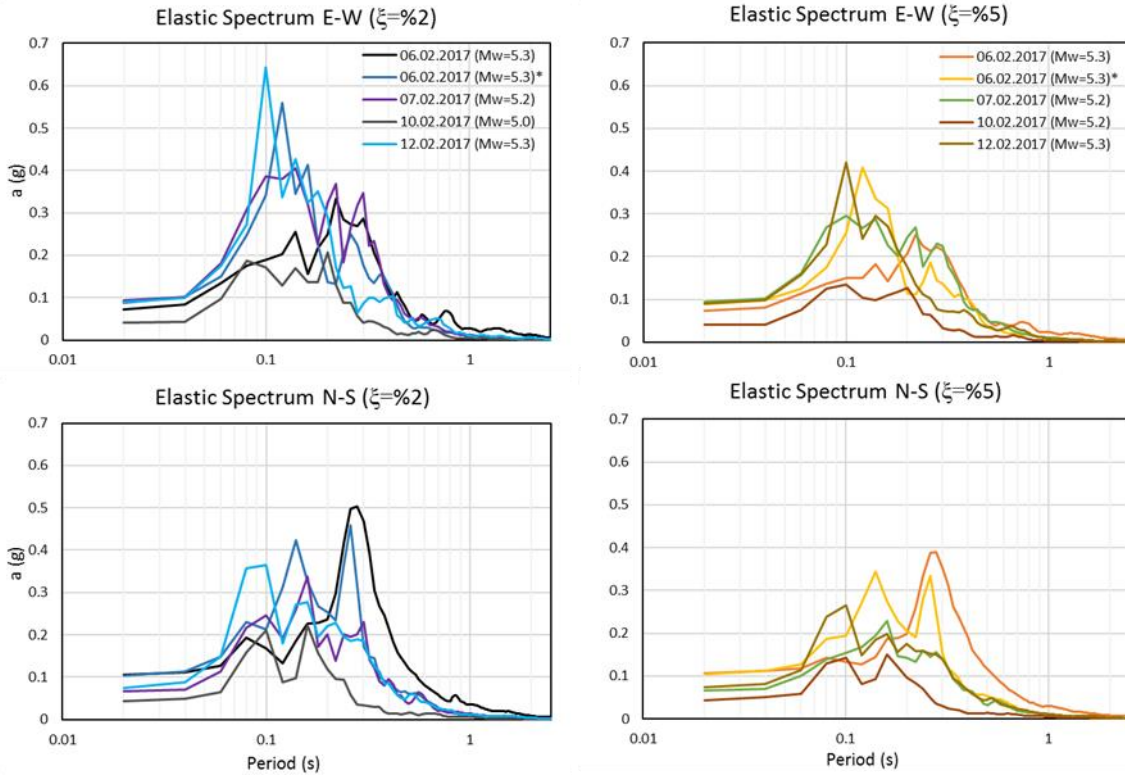
*This earthquake is the second earthquake that occurred in the same day having a magnitude of 5.3

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

5    The peak ground acceleration (PGA) values of Ayvacık records are indicated on ~~prepared~~ the attenuation curve prepared 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~~epicentre of the earthquakes, the attenuation relation point out ~~the~~ that the damaged and collapsed buildings might have experienced 0.2 g and 0.25 g PGA during the earthquakes for rock and soil site conditions, respectively ~~during~~
10  ~~the earthquakes~~. When elastic response spectra calculated by ~~using~~ the Earthquakes and attenuation ~~would be~~is considered, the results show that the maximum acceleration exciting the buildings might reach ~~maximally~~ a maximum of 0.25g in the reconnaissance area. On the other hand, the damping ratio ~~maximally get~~can reach a maximum of 5% for such masonry and adobe structures according to the Turkish Earthquake Code, however, ~~offered the~~ design acceleration is offered as 0.5g in this region for ~~the~~ masonry buildings. ~~Even t~~This comparison is the best evidence we have indicating that damaged or
15  collapsed buildings did not ~~get~~ receive any engineering service or were not built ~~considering any code rule~~ according to code of conduct.
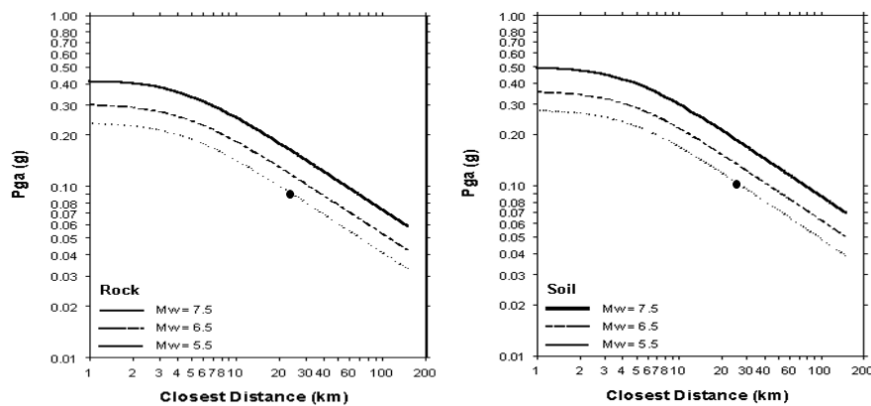
**Figure 8:** Curves of peak acceleration versus distance for magnitude 5.5, 6.5 and 7.5 earthquakes at rock and soft soil sites (Gülkan and Kalkan, 2002)

## 4 Evaluation of Damages profile

5   The damages wereare investigated in two separate subsections. AtIn the first subsection, damage distribution according to affected villages and type of structures arewas addressed; while in the latter, occurred damage modes and their technical reasons arewere evaluated.

### 4.1 Damage distribution

Since, the energy release was relatively very small comparing compared to the earthquakes that occurred on NAFZ or on
10   EAFZ, the other most active zone EAFZ of Turkey, no RC structures collapsed in the area other than the poorly constructed stone masonry dwellings in rural areas. According to the data obtained from Çanakkale Provincial Directorates of Environment and Urbanization, in twenty-nine villages alone, where there were about 27605O damaged or collapsed buildings out of 5790 structures while 3083 structures did not experiencesuffer any damagemore than 25% of the mansion or dwelling either collapsed or were heavily damaged. According to official estimates, within the affected area, a total of
15   146705 (25%) structures (including buildings, houses, barns, offices, stores and haylofts) were heavily damaged or collapsed, and 1235170 (22%) of themstructures suffered medium or minor repairable damage. AlsoMoreover, a total of 30832990 (53%) structures did not experience suffer any damage. The locations of twenty-nine villages together with the epicentersepicentres of considered the studied earthquakes, their magnitudes, and PGAs are given in Figure 9, while the number of damaged structures and damage ratios according towithin these villages are given in Figures 10 and 11,
20   respectively. It can be seen from Figure 9 that Taşağıl, Yukarıköy and Çamköy, etc. as well as Gülpınar are close to the epicentersepicentres of earthquakes, although structures located in the town of Gülpınar town has experienced significantly less significant damage than other villages close to the epicentersepicentres (Figure 11). This resultsThese results may relate

to the construction ~~technies~~techniques and development level of Gülpınar, which are ~~higher~~more improved than the other villages.

~~Also, distribution maps of buildings according to percentage for damage levels are given in Figures 12, 13 and 14, respectively. According to this figures, 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 (Figure 14). 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 villages affect the quality of the construction. Thus, the structural damage was concentrated mainly in the villages which have relatively very low economical level and where there are not any engineered buildings observed by the authors.~~
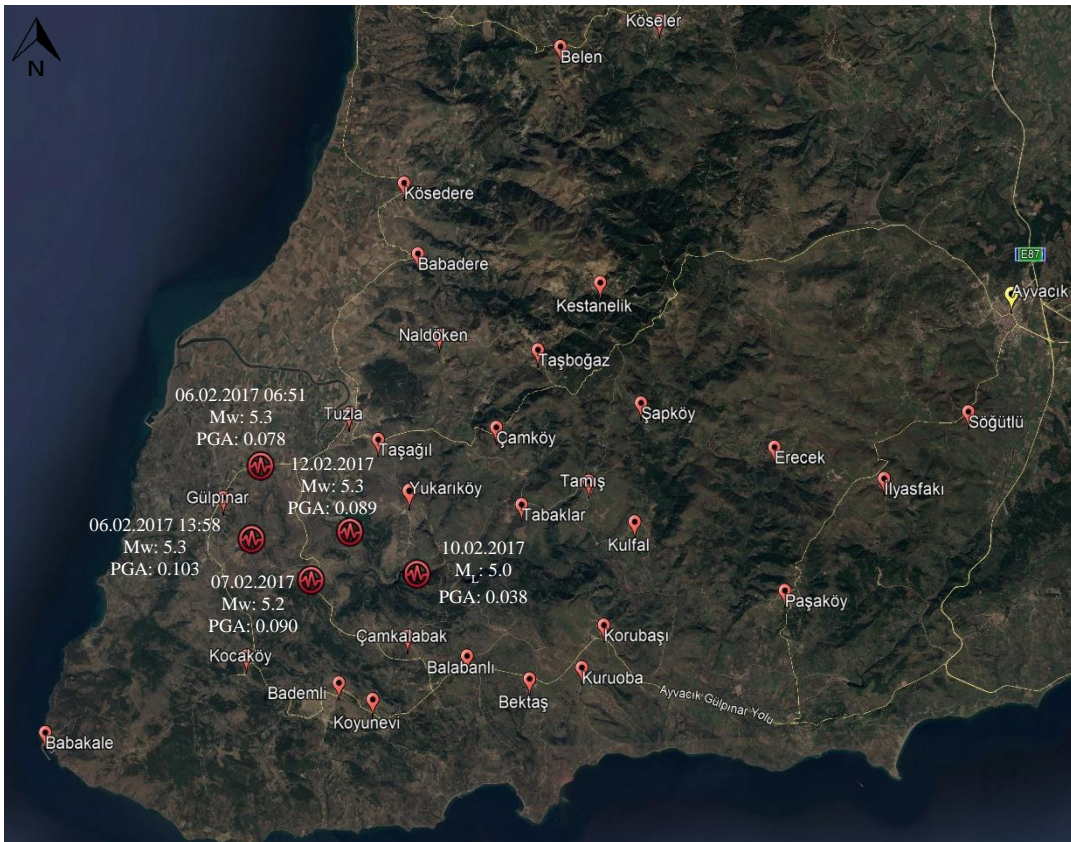


**Figure 9: Villages affected ~~from~~ by Ayvacık earthquake~~s~~ swarm and locations of investigated earthquakes**
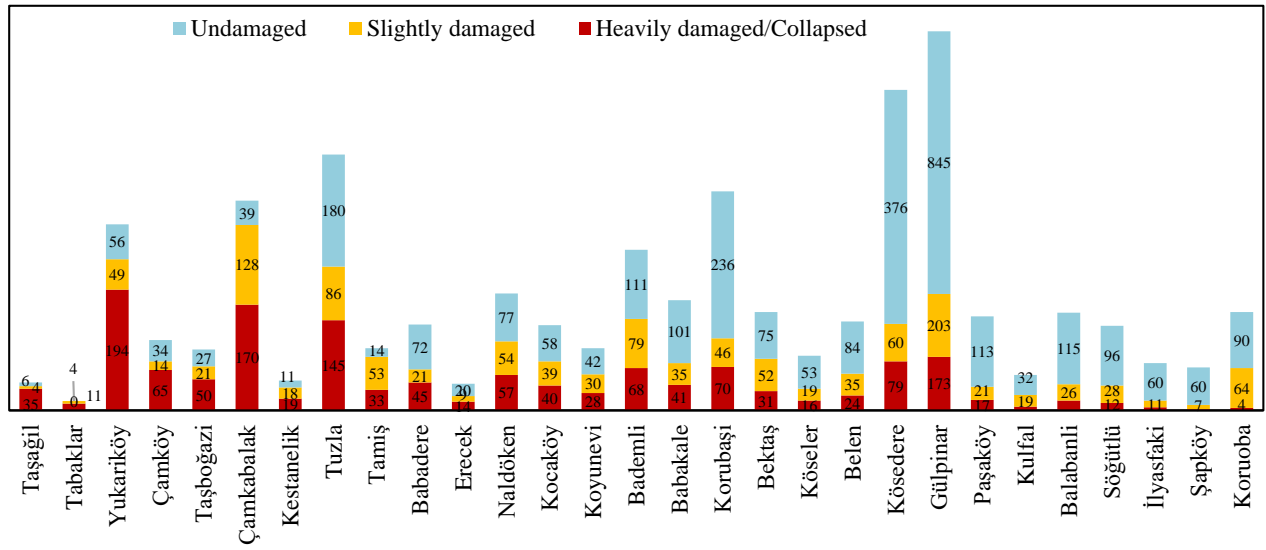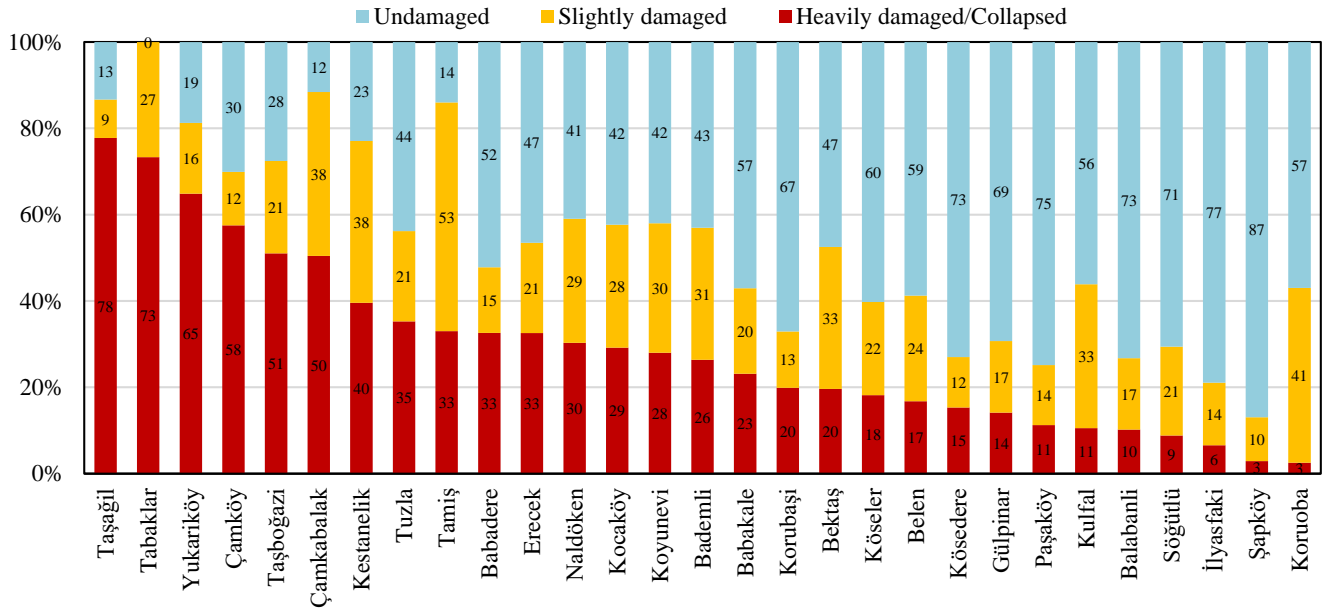
**Figure 10: Number of buildings according to damage level due to Ayvacık Earthquake swarm**



5 **Figure 11: Damage ~~ratio~~ratios in Villages according to damage level due to Ayvacık Earthquake swarm**

~~Also, d~~Distribution maps of buildings ~~according to percentage for~~in percentages according to damage levels are given in Figures 12, 13 and 14, respectively. ~~According to t~~These~~is~~ figures~~, more clearly indicate~~clearly indicate that the percentage of heavily damaged/collapsed structures in Gülpınar was lower than other villages close to the epicentres that suffered significant damages. The reason for this can be explained by Gülpınar being a historical town centre in the region, therefore the town contain cultural heritage sites. The differences in terms of cultural accumulation and development level between Gülpınar and other villages subsequently affect the quality of construction. Thus, structural damage was more prominent in the villages with relatively low economical development, and where there are no engineered buildings as observed by the authors. ~~that structures in Gülpınar experienced rare heavily damaged/collapsed level while several structures in villages close to the epicenter suffer significant damage level. The reason of this situation is that~~ ~~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 (Figure 14). 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 a 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 villages affect the quality of the construction. Thus, the structural damage was concentrated mainly in the villages which have relatively very low economical level and where there are not any engineered buildings observed by the authors.~~
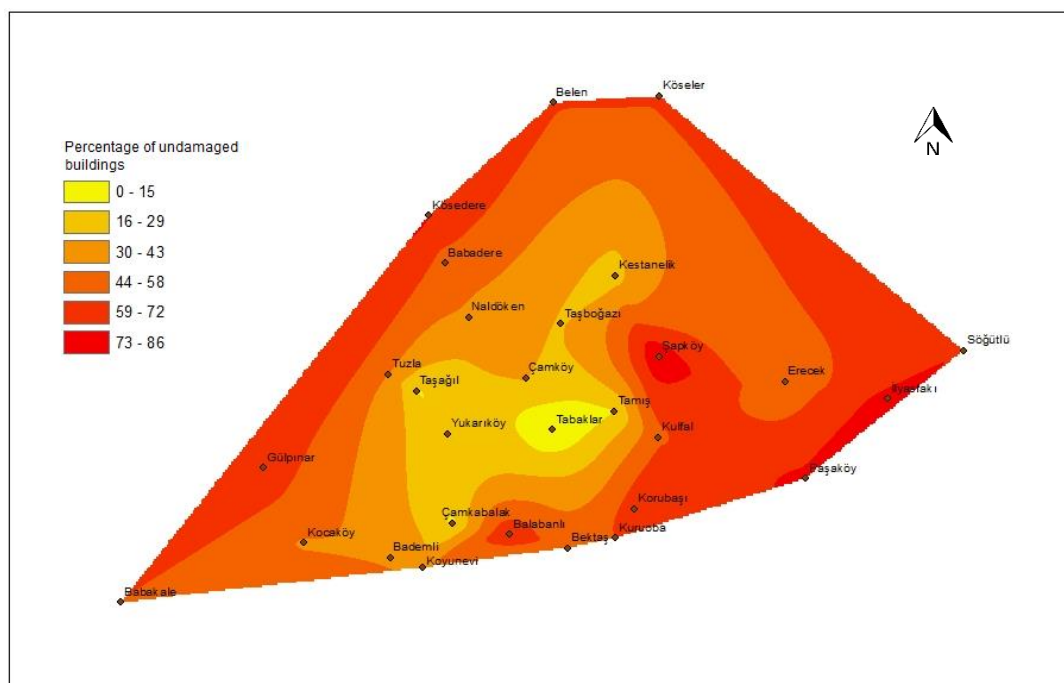


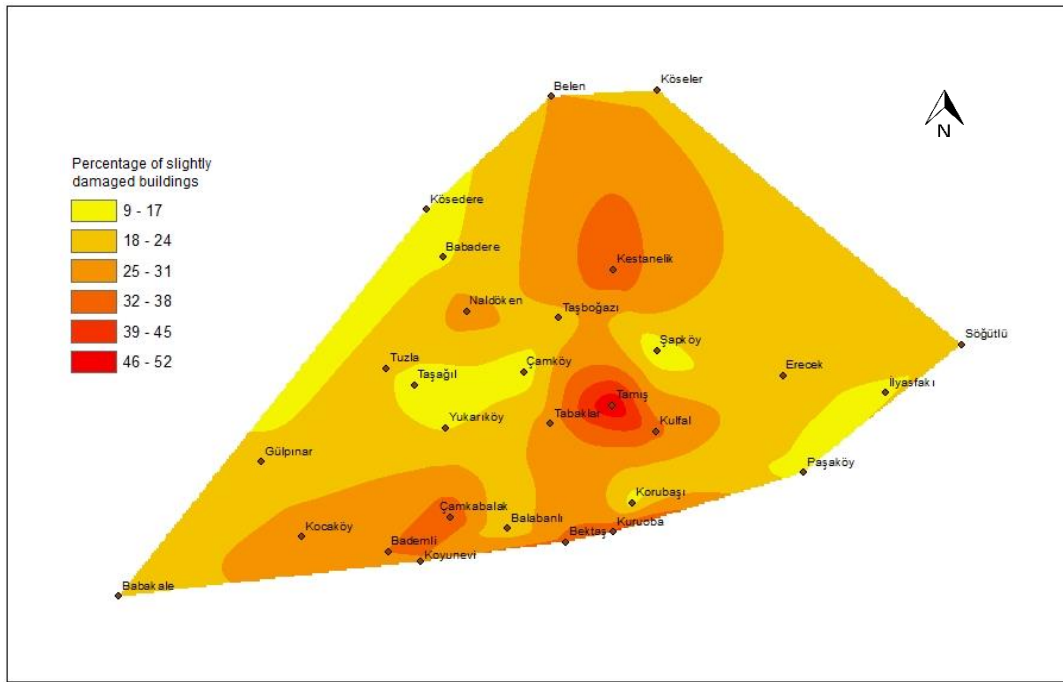**Figure 12: Distribution maps of undamaged buildings ~~according to~~in percentage**

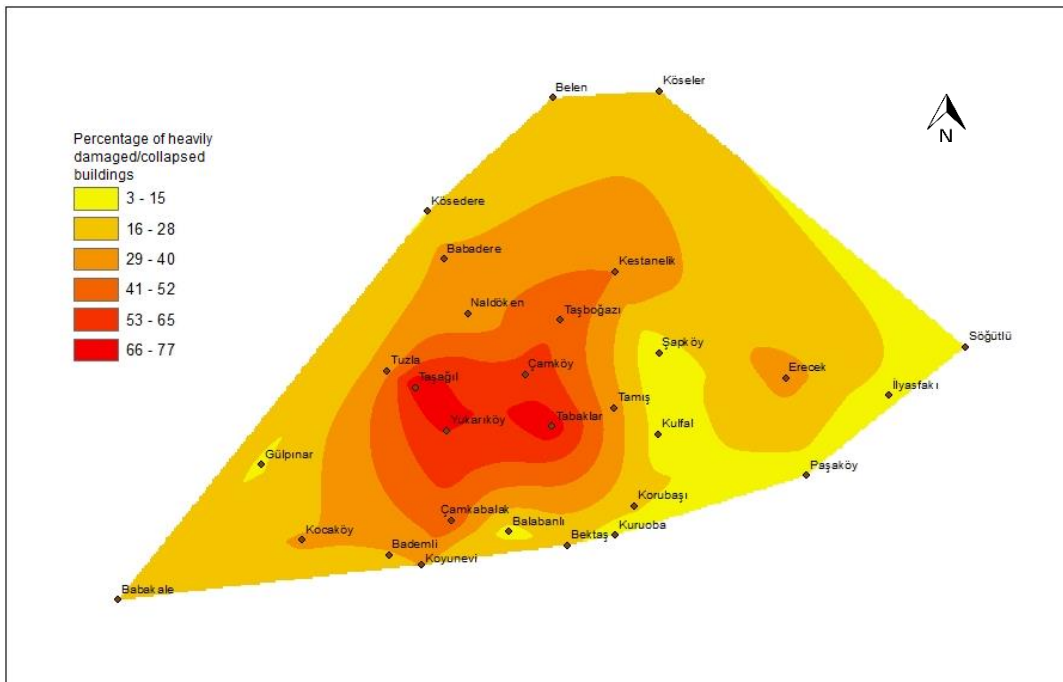**Figure 13: Distribution maps of slightly damaged buildings ~~according to~~in percentage**



**Figure 14: Distribution maps of heavily damaged/collapsed buildings ~~according to~~in percentage**

Distribution maps mentioned above are created for all structures regardless of ~~considering~~the structure types. However, evaluation of damage levels according to structure types may ~~bring~~introduce a new ~~viewpoint~~perspective in ~~order to interpret~~interpreting the damages. Besides, such a parametric study may be a guide in order not to repeat similar mistakes when reconstructing structures ~~having a high ratio of~~with a high heavily damaged/collapsed ~~level~~ratio according to structure types. Damage ratios according to six structure types are generated in Figure 15 with the support of Çanakkale Provincial Directorates of Environment and Urbanization. As can be seen from the figure, the construction practices applied on Haylofts and Barns should be substantially revised ~~for such a possible~~in order to minimize damages from a potential similar earthquake. On the other hand, the ~~technics~~techniques used on structures having ~~approximately %25 ~~a heavily damaged ratio of approximately 25%, such as stores, houses and buildings may be reviewed and enhanced according to technical deficiencies mentioned in the next section. ~~However, o~~It can be seen that office structures experienced relatively less damage compared to other structure types. Thus, it can be said that construction of office structures ~~have closer~~were performed more in line with the conditions required by TEC' 2007.
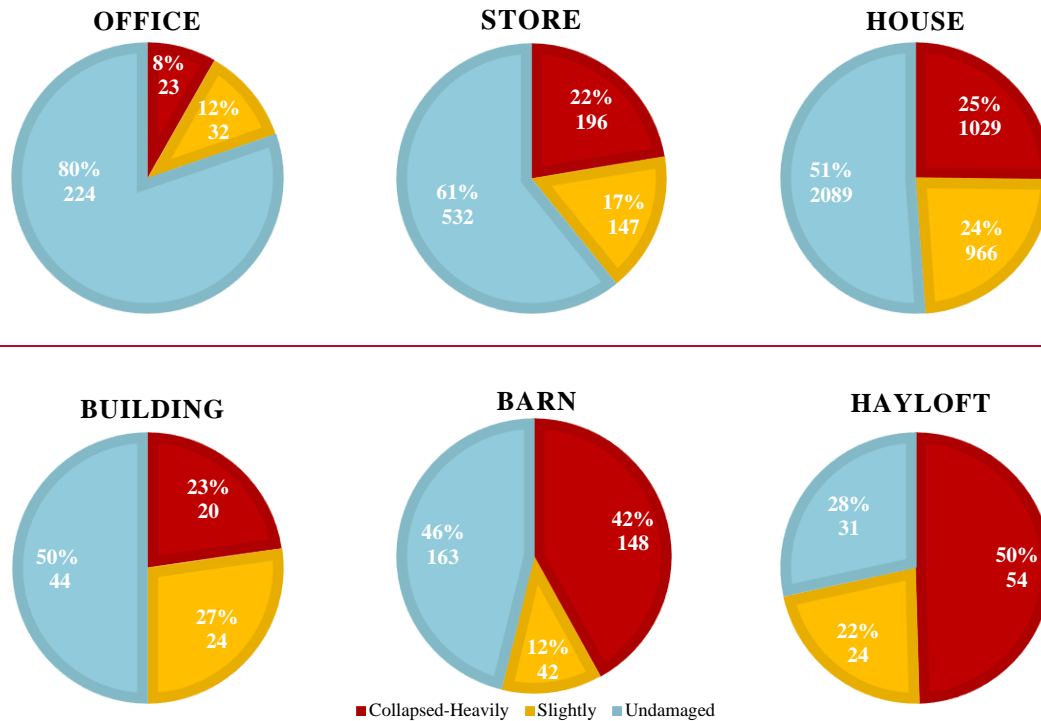


**Figure 15: Damage ratios and levels according to structure type**

## 4.2 Damage profile

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~~and so on~~.~~ (Tezcan, 1996; Bayraktar et al., 2007; Adanur, 2008; Ural et al., 2012). Adanur (2010) showed that ~~in~~ based on the investigations after 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. (2007) reported that 1000 buildings were affected from the earthquake in Doğubeyazıt. Similar to the above-mentioned studies, ~~so~~ thus far, experiences from such moderate earthquakes in rural areas of Turkey have shown that even low-moderate earthquakes may cause significant damages on non-reinforced masonry structures (Fig. 16~~5~~). This type of masonry is among the most vulnerable type of buildings during an earthquake. Even under moderate lateral forces, such a masonry structure is damaged or collapsed~~,~~ due to lack of shear strength, improper interlocking mechanism and/or poor bonding between stone-stone or stone-mortar. In this case, shear failure is unavoidable in the planes forming diagonal cracks or similar cracks suitable for damage along the wall due to workmanship defects. Furthermore, when the wall is not designed with any engineering rule in mind, catastrophic and rapid collapse occurs in out-of-plane bending mode. In addition to the general failure mode mentioned above, the technical causes of damage and crashes observed in the reconnaissance area can be summarized as follows.~~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 in reconnaissance area may be summarized in detail as follows.~~

**Figure 16:.5 Examples of Totally totally collapsed examples structures from Ayvacık, Çanakkale 2017 earthquakes swarm**

- Inadequate interlocking among the stone

In the rural areas of Turkey, the construction of dwellings is done by the owner—occupier tenantdweller with aid the help of craftsmen who live in the locality area but who are not full-time builders. These builders often learn their trade via apprenticeship. Hence, they have their own tools and do not follow any scientific rules on the site, as a result, an outdated or faulty construction technique can stay alive in a small region, and construction becomes highly similar between the dwellings. For example, during field observations, it was understood that even thick mortar or mud was not used as binding agent between stone or masonry units in almost all damaged houses. Figure 17 is a striking example of heavy damage during earthquakes due to lack of mortar between stones. After a few mild earthquakes this masonry dwelling became unstable. 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. 167 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 17616:. An example of a damaged dwelling due to inadequate interlocking**

Another damage type observed in the region is outward bulking of walls, which is caused by interlocking deficiencyinterlocking deficiency. The reason of this deficiency is the vertical gap between stones creating wall thickness as shown in Fig. 187. In order to prevent this damage, horizontal elements such as 'hatıl' or key stone, which provide integrity to masonry walls, can be vertically used in specific intervals vertically. The key stones or 'hatıl's can provide limited resistance to lateral seismic loads, and thus probably prevent the out-of-plan failure on some part of masonry walls.
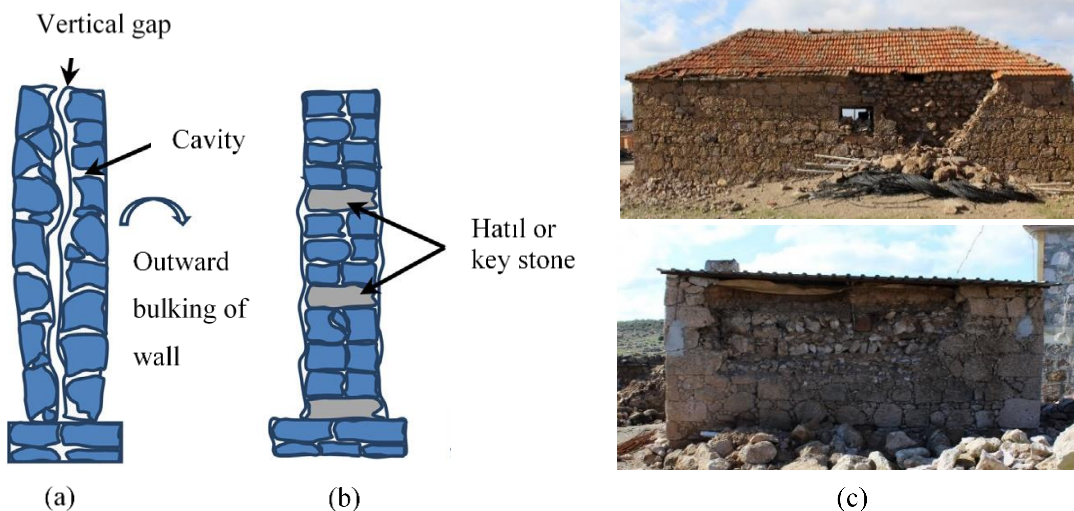


**Figure 18718:. Schematics of (a) conventional wall section without through stone, (b) wall section with through key stones (Sharma, 2016), (c) observed damages observed in the region.**

An~~other~~ ~~additional~~ interlocking damage type is observed at the intersection of perpendicular walls (Fig. 1~~9~~8). One of the walls acts out of plane while the other remains very stiff in plane, resulting in inevitable cracks. ~~Damages in this type~~This type of damage 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~~ stages of this damage may result in out-of-plane failure of gable-end wall. To avoid intersection damage, the interlocking in the corners between perpendicular walls ~~in the corners~~ should be ~~appropriately~~ properly designed against lateral earthquake forces.



**Figure ~~198~~ 19~~:~~. Observed damages at intersection of perpendicular walls**

- Irregular~~ly~~ designed wall with cavity

The design process of ~~the~~ masonry buildings needs ~~to~~ more regularity ~~more than~~compared to other supporting system~~s~~, because the system resisting lateral load~~s~~ ~~resisting system~~ must have continuity and regularity in order to meet shear force~~s~~ ~~stemming from~~created by the earthquake. In ~~the~~ rural area~~s~~, however, traditional fireplace~~s~~ ~~was~~ have been used in ~~the~~ buildings, and ~~it is~~they are built within the wall by decreasing the wall thickness or curving the wall outward. In such a case, irretrievable damage is ~~occurred~~ inflicted on the wall because of ~~the~~ decreasing shear resistance (Fig. 20~~19~~). This damage type was observed ~~for~~ in different masonry structures in the site. ~~For example, it can be seen from Fig. 2019 that there were different examples like~~Different cases such as cut stone masonry, stone with plaster, and stone without mortar can be seen in Fig. 20. The common damage type is most likely ~~stemming from~~caused by the lack of ~~skill of craftsman~~craftsmanship or traditional habits.

17

**Figure ~~2019~~20~~.~~: Examples of out of plane collapse due to wall cavity**

- Heavy Earth Roof

Another important ~~reason that causes~~cause of damage is the roof~~s~~ made from a thick and heavy layer of mud spread upon wooden logs (Fig. 2~~10~~). This technique is widely used in ~~some~~ certain part~~s~~ of Anatolia~~n region~~ where timber is increasingly scarce. These heavy earth roofs are generally ~~made hardening~~hardened by spreading soil with a cylindrical stone. The roof must be thickened more and more over the years ~~To~~to make ~~the earth roof~~it more durable against water leakage ~~need to be thickened more and more over the years~~. Consequently, ~~heavier earth roof cause bigger~~heavier roofs exert larger shear force~~s~~ during ~~the~~ an earthquake. In the investigated area, the roofs were either supported by beams and indirectly by walls or beams of the inner structure, and the columns were round or sub-round in cross-section, and the trunks were without the barks. This made it virtually impossible to obtain good connections and bearing surfaces between the beams. Such beams were prone to rolling off during motions induced by earthquakes. Moreover, the round ends of the beams exerted loads (to an excessive degree) on the supporting walls beneath them, and resulted in the collapse of the earth roof or walls.

~~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.~~

18

**Figure 21:.0 Examples of heavy earth wall collapse**

- ~~insufficient~~ Insufficient wall rigidities

In many cases, distinctive diagonal or inclined cracks ~~have been~~were observed in load-bearing window piers or walls with

5   low width-to-height ratios as a result of inadequate shear resistance (Tomazevic, 1999). While bending and shear forces ~~from created by a~~ moderate earthquake can be easily resisted by reinforced-masonry with lateral and horizontal elements such as RC or timber (Fig. 22~~1~~), the dwellings made ~~by~~ from stone ~~in~~ with no mortar cannot resist the~~se~~m forces. This construction defect ~~is causing~~causes 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.

10



**Figure 22:.1 Examples of undamaged dwellings**

Many weak masonry walls without mortar had diagonal or inclined shear cracking as a result of cyclic shear forces ~~applied~~ exerted during the earthquakes (Fig. 2~~3~~2). 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. 2~~4~~3). Similar failures ~~were~~ have
5  previously been reported around the world (Ural et al., 2012; Klingner, 2006).



**Figure 2~~2~~3~~.~~: Examples of diagonal shear cracking**



10  **Figure 2~~4~~3~~:~~. Out of plane failures ~~depending on~~due to 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~~no reported landslides, or rock fall.


## 5 Conclusions and Recommendations

The aim of this paper is (1) to evaluate the characteristics of earthquakes, (2) to scrutinize the damage distribution in terms of villages and structure types and (3) to investigate the damage and collapse mechanisms observed in buildings during a rarely occurred event called earthquake swarm that struck Ayvacık, Turkey, between 06 ~~and~~ 24 February 2017. This earthquake swarm ~~includes~~ contained more than 1500 earthquakes with some moderate earthquakes (Mw > 5.0). ~~Additionally, t~~The properties of these earthquakes ~~regarding~~ with respect to civil engineering such as peak ground acceleration, response spectrum ~~are~~ were specified. Although the determined elastic spectrum remain~~s~~ed under the design spectrum of TEC (2007), significant damages and failures ~~of~~ in many masonry structures were observed in the reconnaissance area. The reason of these damages and failures observed in the survey can be explained as follows: (1) ~~damaged~~ close proximity of damaged buildings ~~are close~~ to the ~~epicenter~~epicentre of earthquakes, (2) influence of pre-existing cracks on the performance of buildings due to many earthquakes ~~occurred~~ occurring 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~~bonding or connection between structural elements. On the other hand, damage distribution/ratio decrease~~d~~s as ~~moving away from~~the distance from the ~~epicenters~~epicentres of earthquakes increased, except for Gülpınar.

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


## Acknowledgement

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**<u>Response to Dr. Molinari;</u>**

We would like thank to the editor for the time spent in reviewing our article and her valuable comments. Authors tried to present a revised version of the paper, in which most part of the editor's comments were attended and with considerable improvements on the written text. Some revisions are presented in the following pages along with explanations. We have tried our best to accommodate all scholarly comments provided by the reviewer and clarify the ambiguities. We also scrutinized the whole paper and attached new sections to the text to overcome the arisen unclearness through the paper. But It is worth noting that in civil engineering point of view, authors built the goal of the paper to help the engineers to show damages due to local construction types in moderate seismic events and to better understand damages observed in the site. Anyone can easily find similar articles in the literature which give similar results for earthquakes but every observation includes unique damages belonging the area due to the earthquakes and/or special features of the region. In this context we hope the revised paper satisfy the standards of your board.

1. *The first one is the survey. I think that the way in which you conducted the research (how many buildings? In which area? How they were chosen? Why? How many persons involved? Which tools/instruments you implemented? How long does it take?) as well as its objectives (Which are the parameters, aspects, evidences you collected? Why?) must be fully described, also in order to allow other research to repeat the experience and to compare their results with yours. Maps suggested by the first review can support the discussion.*

**<u>Authors Reply:</u>**

a) *How many buildings?*

Number of buildings according to villages are given Figure 10. Moreover, total number of buildings are added to the text as below with updated numbers.

"According to the data obtained from Çanakkale Provincial Directorates of Environment and Urbanization, in twenty-nine villages alone, there were about 2705 damaged or collapsed buildings out of 5790 structures while 3083 structures did not suffer any damage. According to official estimates, within the affected area, a total of 1470 (25%) structures (including buildings, houses, barns, offices, stores and haylofts) were heavily damaged or collapsed, and 1235 (22%) structures suffered medium or minor repairable damage. Moreover, a total of 3083 (53%) structures did not suffer any damage."

b) *In which area?*

The location of the research area is shown with a red star on the tectonic map of Turkey in Figure 5. In addition, locations of investigated 29 villages with earthquakes are given in detail in Figure 9. The Latitudes and longitudes of the earthquakes are given in Table 1 (indicating the area in which the research is conducted).

The authors think that there are enough information explaining the area of the research. However, if the editor has a better or alternative choice, the authors will try to evaluate and improve the value of the paper.

*c) How they were chosen?*

The buildings in selected villages close to the earthquake epicenter are mostly affected from the earthquake swarm. Since almost 6000 buildings were available in the 29 villages, the authors received support from Çanakkale Provincial Directorates of Environment and Urbanization for the official numbers according to damage level (heavily, collapsed etc.). due to this information reconnaissance team including all authors focused on the damaged area. In civil engineering point of view, it is the most important point for the authors that why damages occurred during a moderate earthquake. Observation on the damages and their reasons were tried to express in the manuscript

*d) How many persons involved? How long does it take?*
These questions are answered by revising the first sentence of the last paragraph of introduction as below:

"A field reconnaissance was carried out by four authors immediately after the earthquakes on February 12-17, for a period of five days and the observations were reported in the present paper."

*e) Which tools/instruments you implemented?*

The aim in reconnaissance researches with viewpoint of civil engineering is to observe damage profile and damage level of structural elements of building as well as their causes rather than non-structural elements. For this reason, simple tools are generally used in this type of researches such as laser meter, meter or plumb. The authors do not find necessary to express these simple tools.

*f) Which are the parameters, aspects, evidences you collected? Why?*

One of the objectives of the reconnaissance paper is to investigate and evaluate the damage patterns of buildings and its causes. This is expressed at the last paragraph of the introduction as:

"The objective of field reconnaissance was to record the causes of the damage patterns observed in the buildings, mainly in the rural areas affected by the earthquake swarm."

Another objective is to evaluate the relationship between response spectra and structural damage. This is stated in the 3rd chapter of the paper.

Additionally, damage distribution of structures (Figure 12-14) in terms of villages and structure types as pie charts (Figure 15) according to damage levels are created and inserted to the text in chapter 4.1.

*g) Also in order to allow other research to repeat the experience and to compare their results with yours. Maps suggested by the first review can support the discussion.*

First of all, the authors try to do their best in order to fulfill the editor's advice to improve the quality of the paper. However, this type of papers generally includes damage types and its levels after earthquake in reconnaissance area as well as earthquake characteristics. There are several similar studies in literature such as Sharma et al. (2016), Adanur (2010) and Xiong et al. (2015). Therefore, the scope of the paper contains similar topics to above studies. Maps suggested by the first referee have been already added and explained in chapter 4.1.

> **2.** *The second one concerns results. How can I use collected evidences on damage and its cause? E.g. (1) for calibrating new damage models or validate existing one, in order to improve our risk knowledge of the area? If this is the case, why you did not analyse the relation between hazard and vulnerability? (2) to identify the buildings which are most at risks? How? according to which criteria? (3) to suggest mitigation strategies, e.g. retrofitting, better spatial planning, etc.; what results tell us about this? (4) others?*

**Authors Reply:**

> **a)** *(1) for calibrating new damage models or validate existing one, in order to improve our risk knowledge of the area? If this is the case, why you did not analyse the relation between hazard and vulnerability?*

It is not aimed in this study either calibrating new damage model or validate existing one. This is not in the field of the authors expertise. But if anyone want to study in this object we could support them for any aspects.

> **b)** *(2) to identify the buildings which are most at risks? How? according to which criteria?*

A comprehensive explanation is conducted and added to the paper as below (Figure 15):

"Distribution maps mentioned above are created for all structures regardless of the structure types. However, evaluation of damage levels according to structure types may introduce a new perspective in interpreting the damages. Besides, such a parametric study may be a guide in order not to repeat similar mistakes when reconstructing structures with a high heavily damaged/collapsed ratio according to structure types. Damage ratios according to six structure types are generated in Figure 15 with the support of Çanakkale Provincial Directorates of Environment and Urbanization. As can be seen from the figure, the construction practices applied on Haylofts and Barns should be substantially revised in order to minimize damages from a potential similar earthquake. On the other hand, the techniques used on structures having a heavily damaged ratio of approximately 25%, such as stores, houses and buildings may be reviewed and enhanced according to technical deficiencies mentioned in the next section. It can be seen that office structures experienced relatively less damage compared to other structure types. Thus, it can be said that construction of office structures were performed more in line with the conditions required by TEC' 2007."

> **c)** *(3) to suggest mitigation strategies, e.g. retrofitting, better spatial planning, etc.; what results tell us about this?*

Most of damaged structures in the affected area are constructed with poor workmanship and material quality, construction without any scientific rule or code and lack of tie or connection

between structural elements. Hence, retrofitting these damaged structures can not be logical and economic according to authors observations. Furthermore, one or more retrofitting techniques may require for each damage type mentioned in 4th section of the discussion paper. For this reason, authors consider that retrofitting technique should be investigated extensively rather than suggesting these techniques in conclusion. And this case (adding retrofitting techniques) will cause further extension of the paper and is beyond the scope of the paper.

> *"I think that, at present, results (or better evidences) are simply discussed in a narrative form without any critical analysis of them… which can be the really added value of the research. But, above all, what results tell us which is novel with respect to the state of the art?"*

- As we discussed in the manuscript and responses given here, the structure type used in the site is not common types neither for Turkey nor for the other earthquake zones all over the world. So every observed damages i.e failure examples due to improper interlocking mechanism and/or lack of bonding between stone-stone or stone-mortar give us special failure type for such a regional construction. It is almost not possible to see such connection details in earthquake prone-areas. Besides other a lot of information given in the manuscript only this information will attract readers' attention.

> *"At last, a re-organisation of the contents and a revision by a native speaker are required. The poor English and the fragmented organisation of the manuscript do not help the full comprehension of its main contents."*

- For re-organisation of the paper, introduction is divided into two different sections in earlier revision, as suggested by Dr. Kundak. For a full comprehension of the main contents of the paper, as suggested by the Editor, 4$^{th}$ section of the paper is divided into two separate subsections.

<span style="color:red">The manuscript is scrutinized and rewritten by native speaker according to the comments.</span>

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**Best regards...**