

Seismic damages observed in Cultural Heritage Structures after Simav and Van Earthquakes in 2011

E. Akpınar, H.M. Atalay & H. Erdoğan

Kocaeli University, Turkey

S. Özden

Okan University, Turkey



ABSTRACT:

Turkey is located in a seismically active region and almost whole country is under the risk of damaging earthquakes. The land of the country called “Anatolia” is one of the ancient places in the world that has a unique wealth of cultural and historic heritage. Earthquakes are the worst damaging events for such structures besides the other demolishing incidents such as fire, riots, wars etc. Turkey faced with two damaging earthquakes in 2011 which are the Simav Earthquake on May, 19, 2011 ($M_w=5.7$) in the western and the Van Earthquake on October, 23, 2011 ($M_w=7.2$) in the eastern part of the country. Many of the cultural heritage structures in these regions, along with the other types of structures, experienced different levels of damage. Site observations and investigations to determine the damage level of such structures plays an important role in protection of cultural assets by providing preliminary workout for further retrofitting actions. This study presents the observed damage in various historical structures in two different cities under the effect of two different damaging earthquakes. The crack patterns, fracture mechanisms and failure modes are reported for the individual heritage structures. It is aimed to identify possible damage types in such shear dominant structures and classify them for possible post-earthquake intervention studies.

Keywords: Heritage Structures, Masonry Structures, Structural Damage, Earthquake

1. INTRODUCTION

Turkey experienced two major earthquakes in the year of 2011. The first earthquake occurred at 23:15 (local time) on May 19, 2011 in Kütahya Province located in western part of Turkey (Fig. 1). The magnitude of the earthquake was reported as $M_L=5.7$ ($M_w=5.8$) and the epicentre was declared as about 13 km northeast the town of Simav (39.13 N, 29.08 E) by Earthquake Department of the Disaster Emergency Management Presidency-AFAD ($M_L=5.9$, $M_w=5.7$ by BU Kandilli Observatory And Earthquake Research Institute-KOERI). The peak ground acceleration measured at the town center of Gediz, 31 km from the epicentre, reached 103.92 gals in east-west direction (AFAD). The region is located in the seismic zone I of Turkish seismic zoning map that has an increasing severity level from V to I.

The history of Kütahya dates back to 3000 BC. It should be noted that the region is known as one of the important stopover among the link between Europe and Mesopotamia. Kütahya has been home to various civilizations and cultures throughout the ages such as Phrygians, Lydians, Hittite Empire, Persian Empire, Roman Empire, Byzantine Empire, Great Seljuq Empire and Ottoman Empire. That variety in the civilizations directly reflected to cultural wealth of the city.

The second damaging earthquake in Turkey in 2011, struck the city Van in the Eastern part of the country (Fig. 1) on October 23, at local time 13:41. The epicenter was reported as the Tabanlı Village (38.68N-43.47E) and the magnitude of the earthquake was reported as $M_L=6.7$ by AFAD ($M_L=6.6$, $M_w=7.2$ by KOERI). The peak ground acceleration measured at the city center of Bitlis, 116 km from the epicentre, reached 102 gals in east-west direction (AFAD). The earthquake caused more than 600

dead and about 4000 wounded. Almost 20,000 building were either collapsed or heavily damaged during this destructive earthquake.

Van Province is located at the junction of two main fault formations, namely, North Anatolian Fault (NAF) and East Anatolian Fault (EAF). The surrounding areas of Van is composed of lake, river and land sediments and has layers of loose sand, gravel and clay. Ground water table is high, especially for the areas close to Van Lake. There are well known volcanoes like Nemrut, Suphan and Tendurek in the hinterland of Van.

Van Province was the capital of Urartian Kingdom in the 9th century BC. Later on, the region was controlled by the Armenian Orontids in the 7th century and Persian Emperor in the mid of 6th century BC respectively. Persians, Roman, Byzantine, Great Seljuq and Ottoman Empires were the other well-known civilizations that controlled the city during the history.

This paper summarizes the field observations carried out in both Kütahya and Van regions after the two major earthquakes with an emphasis on the cultural heritage structures.



Figure 1. Locations of Simav and Van on the map of Turkey

2. FIELD INVESTIGATIONS AFTER SIMAV EARTHQUAKE (19 MAY 2011)

2.1. Nasuh Aga Mosque

Nasuh Aga Mosque, which is located in the downtown of Simav, was made constructed by Nasuh Aga, one of the last seigneurs of Ottoman Empire, in 1789 (Fig.2a). The rectangular-planned mosque has a main dome placed at the center of the structure and two small domes supported by peripherals walls and inner arches at both sides of it. Clay and stone bricks were used to mason the structure while the minaret constructed using only clay tiles.

It was seen that the mosque was heavily damaged and almost all arches supporting the main dome have cracks at their crests (Fig. 3). Inner facades of the peripheral walls covered with plaster whereas the outer facades of the walls left as is. It was observed that significant amount of bed joint sliding damage occurred in the walls, which were easily tracked on both plastered and bare facades. Almost all of the cut-stones placed above the windows have cracking and sliding damages.

It was believed that solid masonry walls of which thickness up to 180 cm, pretty thick plaster that implemented in last restoration and symmetrical plan of the structure prevented to total collapse of the structure although heavily damage took in place. The Nasuh Agha Mosque have been decided to shut down for occupancy after the earthquake and retrofitting and strengthening works still in progress today.



(a)



(b)

Figure 2. Nasuh Ağa Mosque



(a)



(b)

Figure 3. Nasuh Ağa Mosque, arches supporting the main dome

2.2. Üzüm Pazarı Mosque

One of the oldest historical structures in Simav is Üzüm Pazarı Mosque which was thought to have been constructed in 1670 (Fig. 4a). The square-planned mosque has a late prayers' porch covered by four perpendicular arches on the main body of the structure on the front side of it. Cut-stone and clay bricks were used to mason the walls of this single-domed mosque. In fact, the mosque was built on inclined soil, and a semi-basement was implemented on one side of the structure (Fig. 4a – left side).

It was observed that the mosque was heavily damaged after the earthquake. Bed joint sliding damage on the peripheral walls was widely taken place in the structure. Especially at the front corner of the semi-basement side, bed joint sliding cracks due to shear action were detrimental as shown in Fig. 4d. Almost all arches covering the late prayers' porch have cracks at their crests spread to the spandrel walls above due to the movement of the pillars (Fig. 4c). It was seen that pivot tiles of some of these arches crushed and dropped down on the floor. Spandrel walls between the window rows have experienced diagonal tension cracks.



Figure 4. Üzüm Pazarı Mosque

2.3. Ulu (Great) Mosque

One of the oldest heritage structures in Simav is Ulu (Great) Mosque (Fig. 5a). Although the construction date is not known exactly, it is thought that the mosque was built in 14th or 15th century. It was written in the records of Ottoman traveller Evliya Chelebi that the mosque renewed in 1578. Cut-stone was used for construction of the main body of the structure and minaret pedestal and clay brick was the construction material for the minaret.



Figure 5. Ulu (Great) Mosque

It was observed that tensile cracks and bed joint sliding cracks took in place in the minaret above the small door opening (Fig. 5a). Top of the sidewalls (the wall next to minaret and opposite one) experienced with partially out of plane movement (Fig 5b). Almost all arches in their crests and pendentif walls (Turkish Triangles) above have tensile cracks (Fig. 5c-d) due to insufficient performance of tension ties. Diagonal tension cracks were seen in the spandrel walls between the window rows.

3. FIELD INVESTIGATIONS AFTER VAN EARTHQUAKE (23 OCTOBER 2011)

3.1. Husrev Pasha Mosque

Husrev Pasha Mosque, which is located in the Southern skirts of the Castle Van, was made constructed by Husrev Pasha in 1567, the Grand Seigneur of Van (Fig.6a). Sinan, the Great Architect, is believed the architect of this square-planned mosque with a single dome. Peripheral walls have a thickness reaching approximately 180cm. The late prayers' porch, which has been lastly renewed in 2007, has a five arch plan layout, having four small domes in between them. The minaret, constructed by the mosque with a continuous stone wall facade, has a square pedestal.

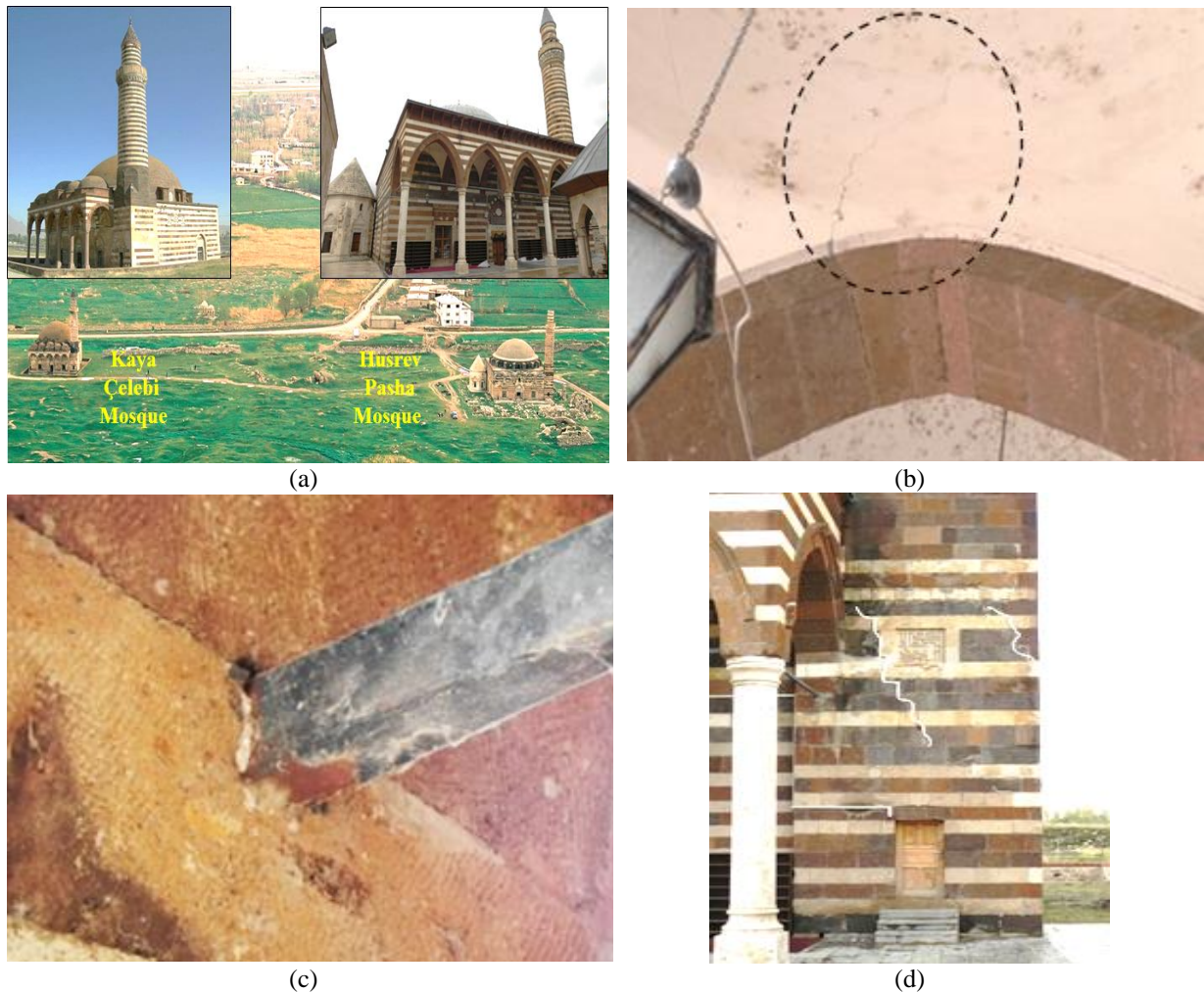


Figure 6. Husrev Pasha Mosque

Tensile cracks were observed in the arch crests (Fig. 6b) spread to the small domes above due to the outward movement of the pillars relative to the peripheral walls. It was believed that such cracking of both the arches and the covering small domes were mainly caused by the insufficient performance of the

tension ties. In fact, the pull-out failure of the tension ties was observed (Fig 6c). Due to the differences in natural frequencies of the minaret and the mosque body, a heavy damage was accumulated on the square pedestal of the minaret, with outward cracks of 45 degrees on both North and South sides (Fig. 6d - north side). Crushing of pedestal wall was also observed on the West facade. The cut-stones just above the entrance door have cracking and sliding on their bed joints.

No damage investigation was allowed inside the structure. Afterwards, it was informed that the late prayers' porch has partially collapsed due to the aftershocks and rest of it and minaret have been demolished to not being hazardous to main body of the mosque. In addition, there was not any remarkable damage in the tomb which was placed next to the mosque.

3.2. Kaya Chelebi Mosque

Kaya Chelebi Mosque which was made constructed by Kaya Çelebizade Koçi Bey around 1660 is the second mosque located in Orta Kapı district, the Southern skirts of the Castle Van (Fig 7a). Main dome of the mosque, which has semi-arches all around, is covered with black and red color Ahlat Stones.



Figure 7. Kaya Chelebi Mosque

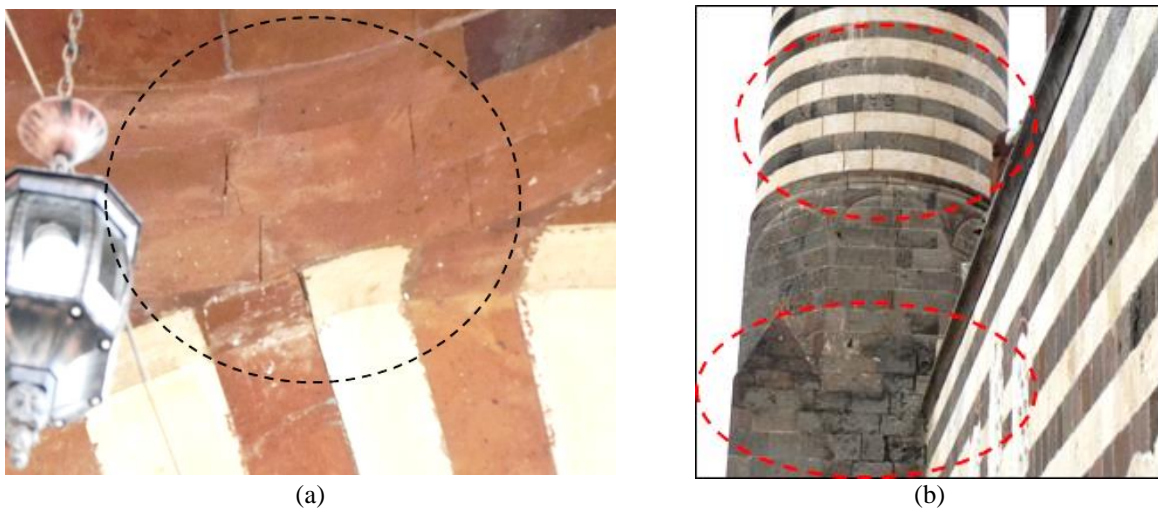


Figure 8. Kaya Chelebi Mosque – further details of damages

Tension ties for the arches covering the late prayers' porch were experienced pull-out type of failure, same as Husrev Pasha Mosque (Fig. 7b). Tension cracks were observed on the arch crests at the late prayers' porch (Fig. 8a) and arches of the windows. Moreover, a very similar shear failure to that of Husrev Pasha Mosque was observed at the pedestal of the minaret (Fig. 8b). However, the stones of the

round part of the minaret also experienced bed joint sliding (Fig. 8b). It was seen that the upper part of the two-colored minaret has toppled (movement was in the East-West direction) and dropped on top of the big dome as well as the semi-arches around the big dome and the nearest small dome covering the late prayers' porch causing crushing and various level of cracking (Fig. 7a).

Thanks to measurement have been taken shortly after the event (supporting the arches covering the late prayers' porch with timber scaffolds), there was no partially or fully collapse due to aftershocks even though the progressed and widened cracks at the late prayers' porch. It was also informed that the minaret was demolished to not being hazardous to main body of the mosque.

3.3. Mud-brick Masonry House with Timber Ties and Hammam in the Same Yard- Ercis

The mud-brick masonry building and the hammam (Turkish Bath) located on the Van Yolu Street, experienced no significant damage at all whereas many buildings were collapsed at the same location (Fig. 9a). It was learned that the building was constructed before the devastating Erzincan Earthquake in 1939.



Figure 9. Mud-brick masonry building and the hammam in the same yard

The superior performance of such a structure may well be attributed to the horizontal timber beams located approximately at every other meters in elevation, if not their continuity at the wall corners. The floors were with logs spanning between the front and back facade wall, resulting one-way load distribution.

Not a definite date was learned for the construction time of the hammam (Fig 9b). The walls and the single dome of the hammam was without significant earthquake damage

3.4. Turkish tobacco and alcoholic beverages company (TEKEL) building

TEKEL building is one of the historical buildings located in the city center on Cumhuriyet Street that was built in early years of Turkish Republic around 1940s. The building is a two-storey masonry structure with a cut-stone façade as shown in Fig. 10a.

No significant damage was observed in the peripheral walls except the back side wall of the building. Damage investigation on the inside the building could not be possible since the building was not in use during the investigation. The back side of the building has a set-back, resulting a strong-to-weak axis wall connection. Vertical crack was observed on the wall due to the displacement incompatibility (Fig 10b).



(a)



(b)

Figure 10. General view of Tekel Building and damage on wall (vertical cracks)

3.5. Tomb of Kadem Paşa Hatun

The tomb of Kadem Paşa Hatun, which was located on the Van Yolu Street at the entrance of Erciş, was constructed out of fine cut stones embellished with floral and geometrical patterns (Fig. 11). The structure itself is one of a unique example of 15th century Seljuqian architecture. It reflects the masonry workmanship of Qara Qoyunlu, also called the Black Sheep Turkomans, tribal federation that ruled the region about hundred years starting from last decades of 14th century.



Figure 11. General view of tomb of Kadem Paşa Hatun and bed-sliding damage

No earthquake damage was observed on the tomb's foundation level. On the other hand, the fine-cut stones were experienced bed-sliding damage above the niche level (Fig. 11). It is believed that the successive earthquakes will increase the bed joint sliding between the facade stones, resulting local collapses. The tomb must be retrofitted immediately against future earthquakes.

4. CONCLUSIONS

Damage observations of cultural heritage structures during two major earthquakes hit Turkey in 2011 were presented in this paper. Almost all of the visited historical structures were heavily damaged. It was believed that insufficient performance of arches especially due to the anchorage problem of tension ties and poor shear behaviour of masonry walls mainly as a result of weakness of mortar were result in such undesired overall performance. Although most of the visited historical structures were renovated in last decades, it seems that the efforts were mainly concentrated on cosmetic aspects. It is obvious that such structures need detailed retrofitting and strengthening efforts too.

5. REFERENCES

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