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19th May 2011 Simav (Kütahya) earthquake and response of masonry Halil Aga Mosque

Ali Ural*

Engineering Faculty, Department on Civil Engineering, Aksaray University, 68400, Aksaray, Turkey

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Abstract. The May 19, 2011 an earthquake hit Simav (Kütahya) province in Turkey. Simav is a district of Kütahya located 255 km southwest from capital city of Turkey. According to Turkish General Directorate of Disaster Affairs (DAD), the magnitude of this moderate earthquake was 5.7. The major percent of the housing stock in the affected region was built in masonry. Many masonry dwellings, mosques and also minarets were heavily damaged due to this seismic activity. The Halil Aga Mosque and its minaret were also heavily damaged as a masonry structure around the earthquake region. In this paper, a site survey of masonry damages is presented and Response Spectrum Analysis of the Halil Aga Mosque is performed using the finite element method.

Keywords: structural damages; simav (Kütahya) earthquake; masonry buildings; strong ground motions

1. Introduction

Many masonry structures located on seismically active regions of Turkey are generally vulnerable during seismic activities. On May 19, 2011, an earthquake of magnitude of ML=5.7 occurred approximately 15 km NE from the district of Simav (Kütahya) with focal depth 24.46 km. Although it was a moderate size earthquake, substantial damage was observed in masonry structures in the rural epicentral region. The death toll was 2 and over 70 people were injured and 2052 households were heavily damaged or collapsed according to the early observations. This earthquake was also felt in neighbor provinces and wide range, Afyon, Bursa, Bilecik, Denizli, İzmir, İstanbul, Ankara and it caused damages at some structures.

Many destructive earthquakes occurred in Turkey during last century and many people died or badly suffered due to these ground motions (Cagatay 2005). Several studies have been performed on seismic damage surveys of masonry building structures. Celep *et al*. (2011) studied failures of masonry and concrete buildings during the March 8, 2010 Kovancılar and Palu (Elazığ) Earthquakes in Turkey. The most important conclusion from this study is that if a minimum amount of engineering attention had been paid during the construction stages, most of the existing buildings could have sustained the earthquakes without considerable damage. Çetinkaya (2011) has also presented a site survey of the damaged buildings due to the same earthquake and

*Corresponding author, Assistant Professor, E-mail: uralali@gmail.com

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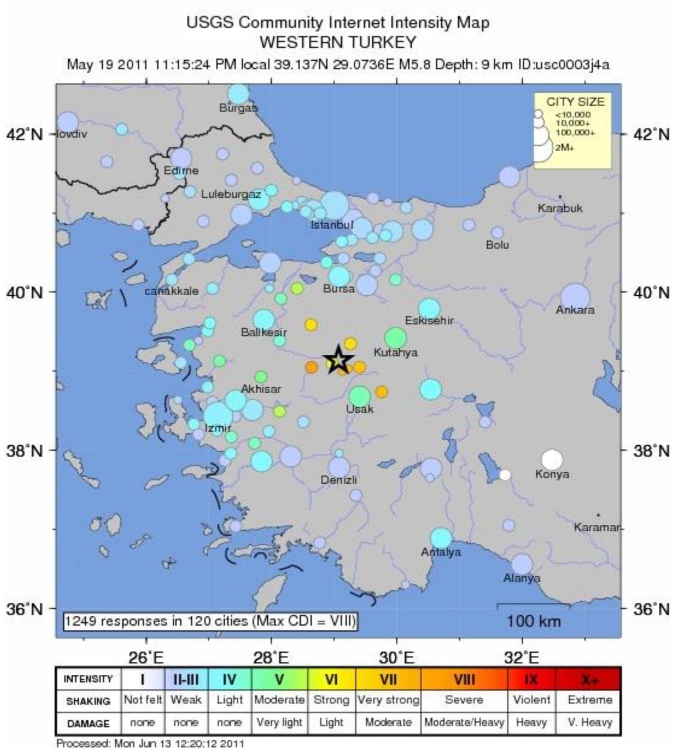


Fig. 1 Intensity map by the 2011 Simav earthquake (USGS 2011)

discussed the causes of structural damages. Doğangün *et al*. (2008) were discussed the seismic performance of masonry buildings during earthquakes between 1992 and 2004 in Turkey. Doğangün and Sezen (2012) were discussed the seismic damage and vulnerability of five historical masonry structures after the 1999 Kocaeli and Duzce, Turkey earthquakes. Besides, Pagnini *et al*. (2011) discussed a mechanical model for the vulnerability assessment of old masonry buildings. Bayraktar *et al*. (2007) investigated the behavior of masonry buildings during the July 2, 2004 Doğubayazit (Ağrı) earthquake in Turkey. Besides, many researches have focused on the seismic behavior of RC or masonry structures with numerical or experimental studies. Kaplan *et al*. (2008) presented a site survey of damaged unreinforced masonry structures due to Çameli Earthquake occurred on 29th October 2007. Both Adanur (2010), Ural *et al*. (2012) discussed the masonry damages, which were suffered during 20th and 27th December 2007, Bala (Ankara) Earthquakes. Besides Doğangün *et al*. (2008), Sezen *et al*. (2008), Altunışık (2011) were studied on dynamic response of masonry minarets.

Historical structures are the most invaluable reflections of our cultural heritage and cultural identity, both of which have significant roles to create a strong link between the past and the present. It is not possible to understand, interpret and retrace the period of civilization without them.

In order to carry out site investigation and damage assessment caused by the 2011 Simav Earthquake, the author visited at the district of Simav (Fig. 1) and nearby villages.

The earthquake caused some significant damages on masonry building structures. Magnitudes of the earthquake taken from different stations are summarized in Table 1. The observations and

Table 1 Magnitudes of the earthquake from different institutions/directorates (Doğangün *et al.* 2013)

Source	Time (GMT)	Latitude (N)	Longitude (E)	h_{hypo} (km)	M
KOERI[a]	20:15:22	39.152	29.088	8.0	5.9
USGS[b]	20:15:22	39.137	29.074	9.1	5.8
DAD[c]	20:15:22	39.133	29.082	24.46	5.7
EMSC[d]	20:15:24	39.150	29.100	7.0	5.8

[a] Kandilli Observatory and Earthquake Research Institute.
[b] United States Geological Survey.
[c] Turkish General Directorate of Disaster Affairs.
[d] European-Mediterranean Seismological Center.

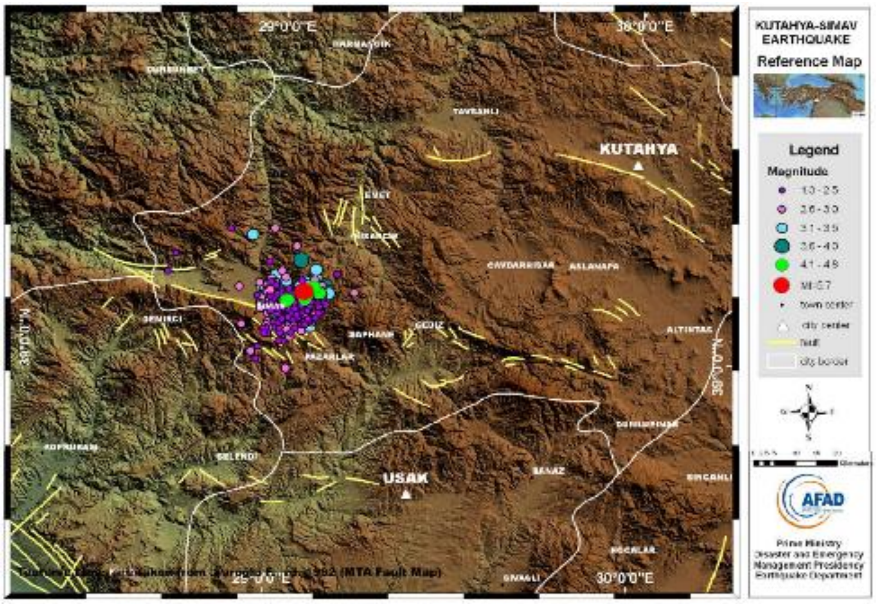


Fig. 2 2011 Simav (Kütahya) Earthquake and aftershocks (AFAD 2011)

assessment of the damage are presented on the following parts of the paper. In this paper, the structural damage observed is discussed considering the strong motion data provided by the Turkish General Directorate of Disaster Affairs.

2. Seismological aspects

This region is very active in terms of seismicity. It is known that damaging earthquakes have occurred in this region. The main faults that cause earthquakes are Gediz-Emet Fault Zone, Simav Fault Zone and Kütahya Fault Zone. The biggest earthquakes that occurred in the last century are 1928 M= 6.2 Emet, 1944 M=6.2 Şaphane, 1970 M=7.2 Gediz and 1970 M= 5.9 Çavdarhisar earthquakes.

According to AFAD (2011), after main shock on May 19, 470 earthquakes were determined with magnitude range 1.3 – 4.8 between 19.05.2011-21.05.2011 (Fig. 2).

Table 2 Peak acceleration values from different stations

Station info			PGA (cm/s^2)			Distance to epicenter (km)
Name	Latitude (N)	Longitude (E)	NS	EW	UD	
Simav dir. Meteo.	39.09282	28.97848	71.18	115.58	323.4	10.00
Emet dir. Highways	39.33612	29.24905	74.69	73.13	46.34	26.76
Gediz dir. Meteo.	38.99478	29.40040	92.33	103.92	67.83	31.52
Uşak dir. Meteo.	38.67128	29.40401	47.87	46.91	23.14	58.30
M. Kemal Paşa dir. Forests	40.03471	28.39392	29.40	61.91	16.74	116.16

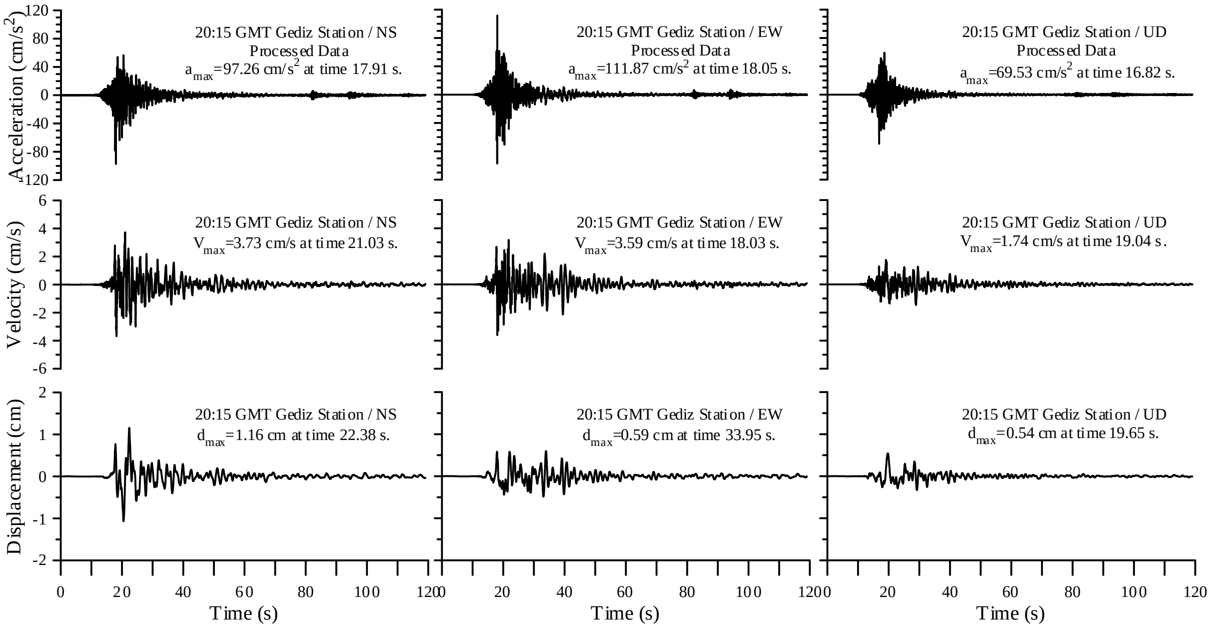


Fig. 3 Acceleration, velocity and displacement histories of Simav (Kütahya) Earthquake on May 19, 2011 (Doğangün *et al*. 2013)

The current Turkish Earthquake Code (TEC 2007) specifies four seismic zones in Turkey. Zone 1 is the most hazardous and Zone 4 is the minimum hazardous zone. Simav is located in Zone 1. The code requires a design acceleration of 0.4g for load-carrying walls and buildings located in Zone 1 (g is the gravitational acceleration). Earthquake Research Center of the Turkish General Directorate of Disaster Affairs has a large number of ground motion recording stations in the region affected by the Simav earthquake. The maximum ground acceleration recorded from the Gediz station on May 19, 2011 was (0.103g) on the EW direction. The measured maximum accelerations are still lower than the design acceleration specified by the TEC (2007). The parameters and the three components of the peak ground accelerations recorded by different stations are summarized in Table 2. Only the records from Simav directorate of meteorology station did not continue recording due to the cut of electricity during the main shock.

In this paper, acceleration records (Fig. 3) and response spectrums (Fig. 4) of the 2011 Simav earthquake are obtained from the Gediz directorate of meteorology station measures.

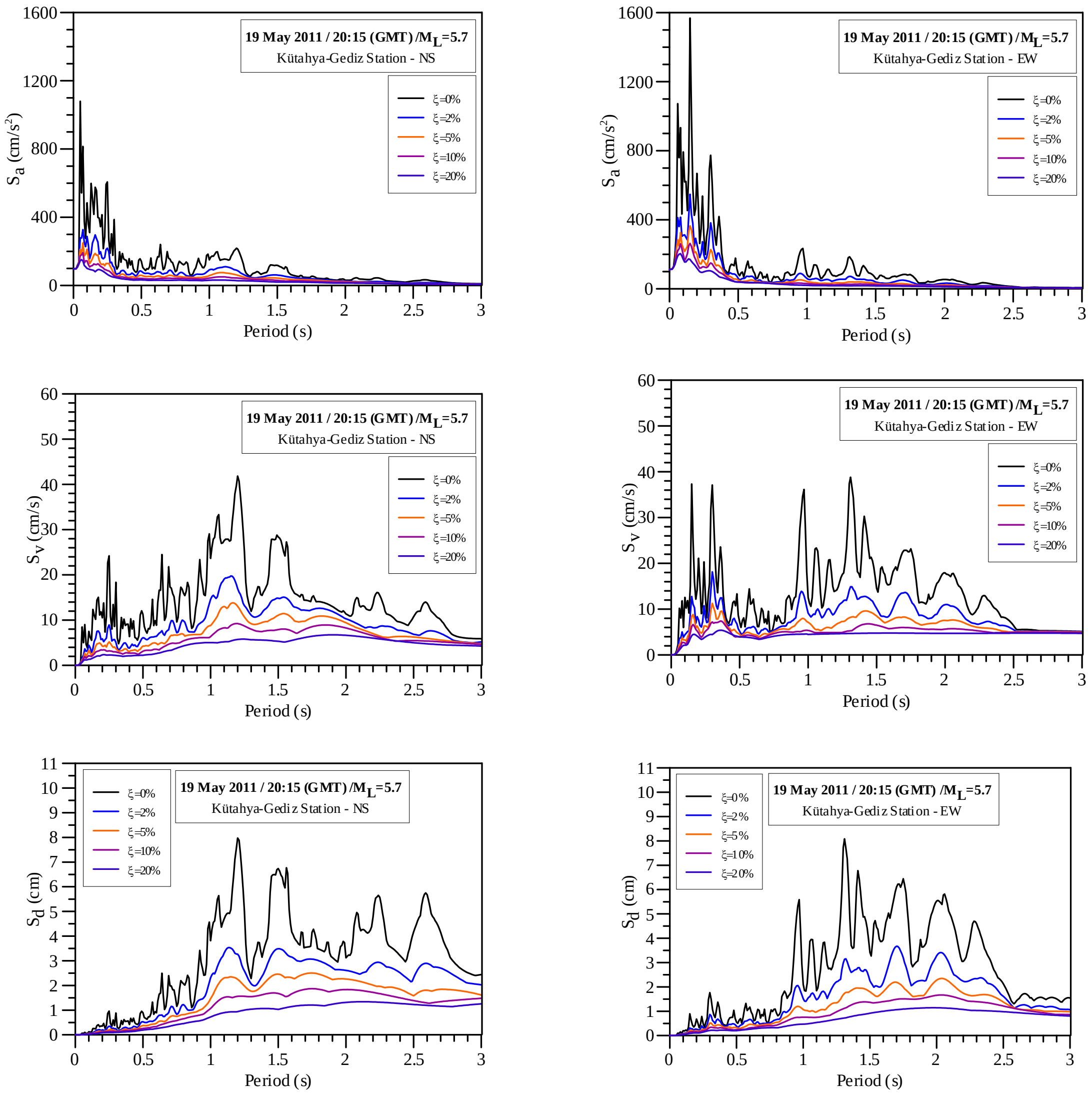


Fig. 4 Spectral acceleration, velocity and displacement responses of the main event for different damping ratios (Doğangün *et al*. 2013)

According to the processed data from Fig. 3, peak ground accelerations of three components vary between 111.87 cm/s^2 and 69.53 cm/s^2. Fig. 4 shows the acceleration spectra for the Simav –NS and –EW components of ML=5.7 Simav Earthquake for the damping ratios of ξ=0%; 2%; 5%; 10% and 20%. According to this spectral acceleration values from Fig. 4, start decreasing at about 0.1s and for 0.7 s and larger periods all spectral accelerations are very low.

3. Damages to historical masonry structures

Unreinforced masonry load-carrying system is one of the most popular structural systems

Fig. 5 Shear cracks on the load carrying walls of Halil Aga Mosque

Fig. 6 Severely damage to unreinforced masonry mosque (Ulu Mosque) and example of out-of-plane damage

widely observed and constructed all over the world. Most of the load-carrying walls are composed of clay brick units and mortar and there is no wall reinforcement such as steel reinforcing bars provided within the walls in both vertical and horizontal directions. During the site survey the author found the opportunity to investigate two of the mosques that remain from Ottoman Period and one mosque dating from 1959 in which were composed both stone and brick units. Nasuh Ağa Mosque, which is located at the district of Simav, was severely damaged due to the 2011 Simav Earthquake. Although external load-carrying walls of the mosque was constructed both of stone and brick units, inner parts of it was constructed with only brick units, which has a dimension of 18x8x5cm3. Due to this structure, although the external walls has slightly damaged, the inner parts of the mosque has severely damaged (Fig. 5). Similar damages can be seen from the Ulu Mosque, which was also remained from the Ottoman period. Typical out of plane damage can be clearly seen from the east façade of the Ulu Mosque (Fig. 6).

4. Analyses of some base isolated buildings by Code requirements and by the time histories

Halil Aga mosque was built in 1959. The mosque was burned few times; most recently some parts of it was built reinforced concrete beams and columns. The mosque is at a place dominated by the municipal square, around the state was reorganized and a beautiful monument.

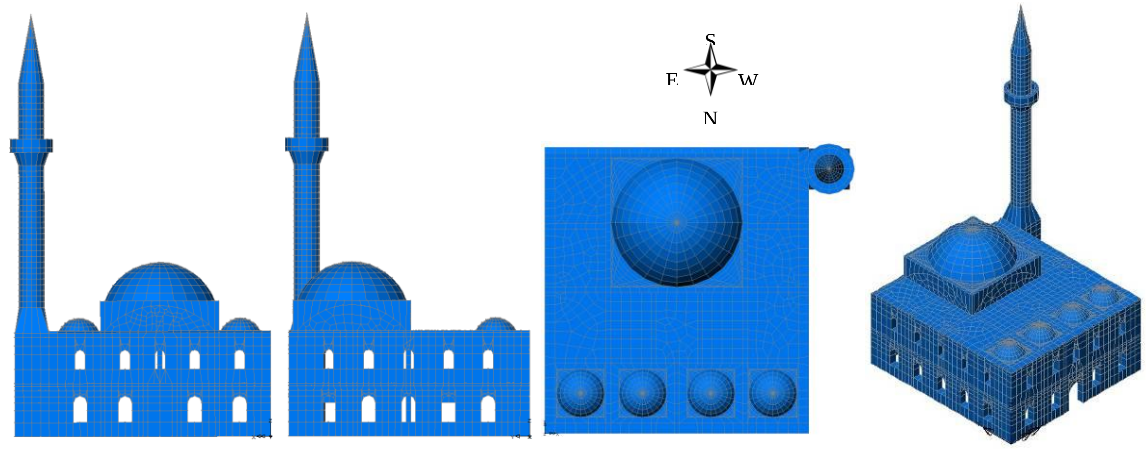
Fig. 7 Shear cracks on the load carrying walls of Halil Aga Mosque

The mosque has two floors and sits in an area of 18 m × 17 m. Total height of the structure is approximately 8.15m and the exterior walls have 0.75m width. The first floor has 16 window openings (1.1 m × 2 m dimensions) and the second floor has 20 window openings (1.5 m × 0.8 m dimensions). Each window has an arch form at the top. The mosque has one main dome and four small domes. The main dome has approximately 9.2 m diameter and 3 m height. Small domes have approximately 3.1 m diameter and 1 m height. The minaret was built adjacent to the mosque and has a 2 m diameter. The length of the pedestal, transition segment, the cylindrical body between transition segment and balcony, upper part of the minaret body between balcony and spire and spire are 8 m, 2 m, 11 m, 6.3 m and 5.3 m, respectively. The average length of the minaret is approximately 32.5 m. This structure was badly suffered during 2011 Simav Earthquake. Shear cracks were dominantly occurred on the façades of the structure. Besides, the masonry minaret was totally demolished after the earthquake due to heavy damage. In order to investigate the seismic response of this structure, linear elastic dynamic response spectrum analyses were performed in the following section of this paper. Some illustrative photos can be seen from the following Fig. 7.

5. Dynamic analysis of Halil Aga Mosque

As mentioned above, Halil Aga Mosque was one of the most damaged structures around the region due to the Simav Earthquake. Determining the dynamic characteristics of this structure, response spectrum analysis has been performed using earthquake data taken from Gediz station of the main event. Gediz station is approximately 37.6 km distance from the mosque. Three dimensional finite element model of the mosque has been developed using the LUSAS 14.7 software (2013). This software can be used for linear and nonlinear, static and dynamic analyses of 2D and 3D model structures. However it cannot be taken into account dynamic analyses with nonlinear material properties. Therefore, analyses have been performed under linear material assumptions. Rayleigh damping with 5% damping ratio is used in the dynamic analyses.

The modeling strategies and material models that used for masonry construction on numerical modeling are very different from reinforced concrete structures. Although reinforced concrete is a heterogeneous material, it is possible to modeling them with same types of finite elements. But masonry is a material which exhibits distinct directional properties due to the mortar joints which



(a) South façade (b) East façade (c) Top view (d) 3D view

Fig. 8 Finite element model of the Halil Aga Mosque.

act as planes of weakness. For this reason, it should be utilized from different modeling strategies for masonry structures. Detailed micro-modeling, Simplified micro-modeling and macro modeling strategies are commonly used for masonry modeling. Further information can be seen from Lourenço (1996). In detailed micro-modeling approach, the mechanical properties of masonry units and mortar are taken into account separately. The probable cracks assumed on the interface line between masonry units and mortar. In simplified micro-modeling approach, each joint, consisting of mortar and two masonry unit-mortar interfaces, is lumped into an average interface while units are expanded in order to keep the geometry unchanged. In macro modeling approach, masonry considered as a composite element after homogenizations of the masonry units and mortar but it treats as a homogeneous anisotropic continuum. One modeling approach cannot be preferred over the other for all cases. Micro models are mainly used for better understanding the local behavior of masonry structures whereas macro models are more practical for the whole masonry systems to reduce time and memory requirements. Further details for these modeling approaches are given in Lourenço (1996). In this paper, the finite element model has been assumed using macro modeling approach due to excessive number of nodes and elements. A total number of 12071 nodes and 6121 elements have been defined for the modeling of the mosque (Fig. 8). The mosque has been considered composed by three different materials for the different structural elements; the masonry walls, the reinforced concrete beams and columns and timber floor slabs.

It is very difficult to determine the mechanical properties of materials used for the historical structures. The author had the opportunity to get some masonry units from the debris of the mosque. According to uniaxial compression tests on samples which performed at laboratory of Aksaray University, Department Civil Engineering, determined properties of the materials are as follows: Modulus of elasticity of masonry, Poisson's ratio and unit mass density are considered as 12000 MPa, 0.2 and 12 kN/m^3, respectively.

The first ten modal periods of the mosque model and their mass contribution to the total dynamic response are presented in Table 3. The calculated first three periods were 0.45, 0.44 and 0.07 s for the mosque model, I, II and III, respectively. The fifth mode contribution to the total response is about 44 percent. The torsional or the seventh mode has virtually less effect on the total response of the mosque.

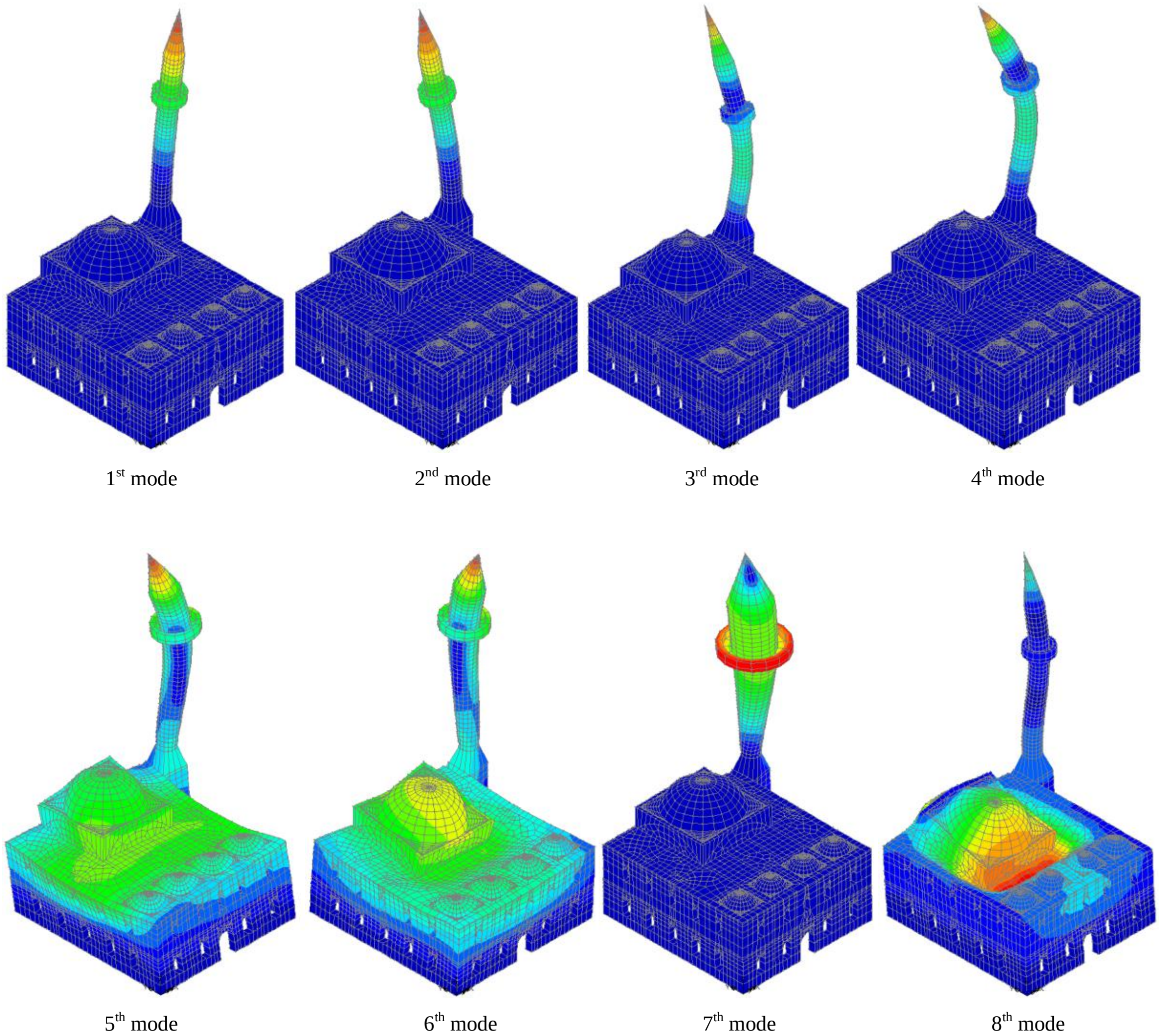
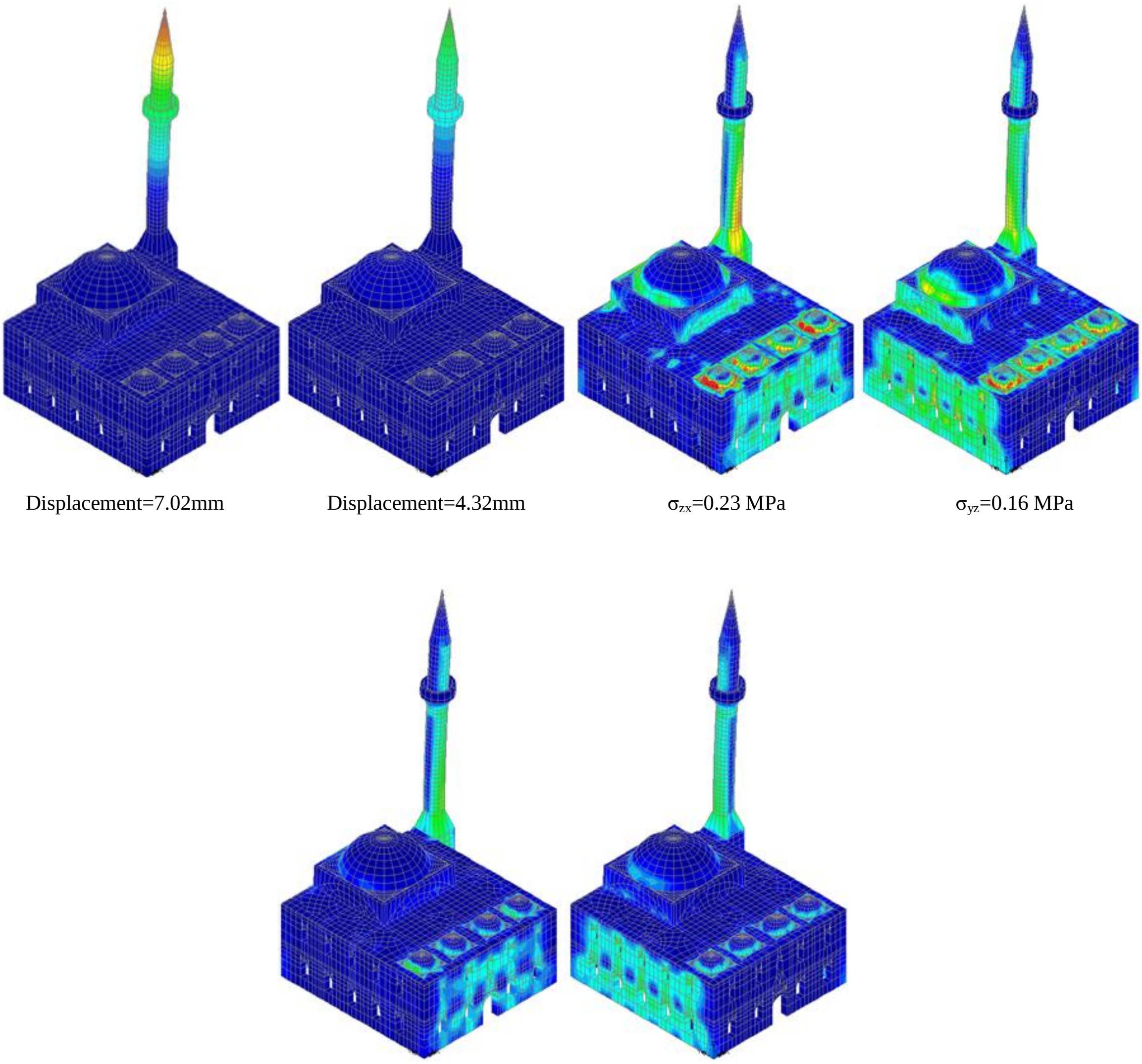


Fig. 9 First eight modals shapes in the two directions and torsional

Fig. 9 shows the first eight mode shapes with displacement contours. According to this figure, only minaret of the mosque was greatly affected on first four modes. Besides, the entire structural model was affected on the fifth and sixth modes.

The elastic dynamic response was carried out by response spectrum analysis for the Halil Aga Mosque with 30 modes. Because approximately 90% mass of the structure is activated by the first 30 modes of vibration. The spectral response was carried out by using CQC combination. Elastic response acceleration spectra for EW component of the Simav Earthquake with 5% damping is taken into account (Fig. 4). The analysis was carried out with the following assumptions; (i) The masonry walls, concrete column-beams and timber slabs are considered as homogeneous and isotropic (ii) The behavior of the model is assumed to be linear elastic (iii) due to the lack of knowledge about local soil conditions, the model is considered fixed at the base. This approach is



Displacement=7.02mm Displacement=4.32mm σ_{zx}=0.23 MPa σ_{yz}=0.16 MPa

ε_{zx}=0.0000388 ε_{yz}=0.0000312

Fig. 10 Response Spectrum Analysis results

used to determine weak zone and region of cracking in the structure. The weak regions imply that zone where there is a concentration of maximum shear stresses. Fig. 10 shows the deformed mesh of The Halil Aga Mosque from response spectrum analysis.

The lateral displacements both on X and Y directions, as calculated from the response spectrum analysis, were 7.02 and 4.32mm for the Simav Earthquake. Displacement of the minaret is naturally higher than the main body. Due to the large window openings in the masonry walls, the shear strength was exceeded and macro level cracks were occurred. The direction of the application is on X-direction as the real earthquake (EW component). As a result of this, masonry walls parallel to the direction of the earthquake were more damaged and this situation can be seen

Fig. 11 Shear cracks on the façade of the masonry mosque

Table 3 The first ten modes and their mass participation factors

Mode number	1st	2nd	3rd	4th	5th	6th	7th	8th	9th	10th
Direction	*y*	*x*	*y*	*x*	*x*	*y*	*Torsion*	*z*	*x*	*y*
Period (s)	0.45	0.44	0.07	0.07	0.05	0.05	0.05	0.04	0.04	0.03
Mass participation factor (%)	2.89	2.84	3.02	3.44	44.03	42.77	2.22	16.68	1.67	3.53

from the results of FEM analyses and from the following Fig. 11. There were few damages around the corners, because window openings are not close to this area.

Besides, Fig. 10 shows the shear concentrations both ZX and YZ directions on the external walls of the mosque. Masonry minaret was severely affected according to this seismic excitation and it was badly damaged.

6. Conclusions

A moderate earthquake of magnitude of ML=5.7 was struck the district of Simav (Kütahya) on May 19, 2011. Due to the lower focal depth of the seismic activity, the structural damages on masonry buildings occurred in a limited area. This paper mainly discusses the damage mechanisms of masonry structures and dynamic response of Halil Aga Mosque in the earthquake-affected areas. The main conclusions inferred from this study are given below:

- Many of masonry damages are attributed to the following items in order of importance; Inadequate masonry units, poor mortar, lack of vertical confining elements, irregularities in plane and vertical directions, inadequate connection and insufficient length of load-carrying walls, unconfined gable walls and heavy cantilever elements.

• From the modal analysis of Halil Aga Mosque, a total of 10 periods were obtained with a range between 0.45-0.44 and 0.07-0.03s, respectively. When the first ten modes are examined, the first six modes and last three modes are horizontal modes in the x and y directions and the seventh mode is a torsional mode. Besides, first four modes are mainly effect only the minaret. Therefore, mass participation factor remain at low levels. This factor increased with the addition of the remained parts of the whole structure.

• An earthquake analysis was performed using 2011 Simav Earthquake acceleration response data. It can be seen from the analysis results, the minaret of the main structure was mainly affected. The maximum horizontal displacements were occurred on the top of the minaret. The mosque was mainly affected due to the shear forces. Therefore, dominant shear stresses were occurred on the façades of the structure between window openings.

• According to the conversation with the city manager, they intended to destroy this damaged mosque. However, this structure can be survived with some simple strengthening methods.

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