Earthquakes and Structures, *Vol. 10, No. 6 (2016) 1331-1346*
DOI: http://dx.doi.org/10.12989/eas.2016.10.6.1331

A study on seismic behaviour of masonry mosques after restoration

Ahmet C. Altunışık*[1], Alemdar Bayraktar[1] and Ali F. Genç[2]

[1]Department of Civil Engineering, Karadeniz Technical University, Trabzon, Turkey
[2]Department of Civil Engineering, Karadeniz Technical University, Of Technology Faculty, Trabzon, Turkey

(Received July 8, 2015, Revised September 2, 2015, Accepted September 30, 2015)

Abstract. Historical masonry structures have an important value for cultures and it is essential for every society to strengthen them and confidently transfer to the future. For this reason, determination of the seismic earthquake response, which is the most affecting factor to cause the damage at these structures, gain more importance. In this paper, the seismic earthquake behaviour of Kaya Çelebi Mosque, which is located in Turkey and the restoration process has still continued after 2011 Van earthquake, is determined. Firstly the dynamic modal analysis and subsequently the seismic spectral analysis are performed using the finite element model of the mosque constructed with restoration drawings in SAP2000 program. Maximum displacements, tensile, compressive and shear stresses are obtained and presented with contours diagrams. Turkish Earthquake Code and its general technical specifications are considered to evaluate the structural responses. After the analyses, it is seen that the displacements and compressive/shear stresses within the code limits. However, tension stresses exceeded the maximum values at some local regions. For this mosque, this is in tolerance limits considering the whole structure. But, it can be said that the tension stresses is very important for this type of the structures, especially between the stone and mortar. So, some additional strengthening solutions considering the originality of historical structures may be applicable on maximum tensile regions.

Keywords: historical masonry structures; Kaya Çelebi mosque; restoration; seismic earthquake response; seismic spectral analysis; Turkish Earthquake Code

1. Introduction

The Anatolia has different cultural heritages from Hittite, Roman, Byzantium, Seljuk and Ottoman, especially, theatres, hippodromes, cisterns and churches from the Romans and Byzantines; mosques, bridges, caravansary, minarets and aqueducts from the Seljuks and Ottomans. The use of masonry carrier system and stone material is the common point of these structures.

Although masonry structures have high compressive strength because of stone material, they have weak performance for horizontal loads, especially seismic loads. The specific configuration of masonry buildings and the mechanical properties of the masonry material characterised by very

*Corresponding author, Associate Professor, E-mail: ahmetcan8284@hotmail.com

http://www.techno-press.com/journals/eas&subpage=7 ISSN: 2092-7614 (Print), 2092-7622 (Online)

low tensile strength caused seismic vulnerability. Although masonry structures are often designed to ensure structural shape and integrity to resist gravity loads, this type of design is not sufficient to resist horizontal forces due to seismic events (Brandonisio *et al*. 2013).

Earthquake is sudden and rapid shaking of the earth caused by movement of tectonic plates and faults. These movements create stresses in time and finally caused earthquakes which release the accumulated energy suddenly. Turkey is in very active region about seismic actions because it is on the Anatolian Tectonic Plate which is surrounded by the Arabian Plate, The Eurasian Plate, and the African Plate. The movement of these plates caused hundreds of earthquakes each month (Bayraktar *et al.* 2014). A lot of big earthquakes occurred in this region. Thousands of people died, and many concrete and masonry structures were heavily damaged or destroyed.

Historical masonry structures have an important value for cultures and it is essential for every society to strengthen them and confidently transfer to the future. So, the restoration studies are very important to keep these structures alive. The restoration process needs more attention, more knowledge and more experience. For masonry structures, which are complex and have seismic vulnerability, this issue gain more importance. Before the restoration, structural performance under static and dynamic loads should be determined and related suggestions should be made to obtain the enough stability with restoration.

Many studies can be found in the literature about the seismic behaviour of masonry structures such as mosques, bridges, buildings, towers and minarets. Lourenço and Roque (2006) proposed a fast procedure for safety assessment of historical masonry buildings under seismic loads. For this purpose, 58 Portuguese churches examined for three different simplified safety indexes that are in-plan area ratio, area to weight ratio and base shear ratio. Bayraktar *et al.* (2007) investigated the performance of masonry stone buildings during the March 25 and 28, 2004 Aşkale (Erzurum) Earthquakes in Turkey. Paret *et al.* (2008) examined a historic masonry synagogue in San Francisco for seismic assessment considering strengthening techniques. Akan (2010) evaluated the seismic behaviour of timber pillared historical mosques with the finite element method. Bayraktar *et al.* (2011) studied the seismic behaviour of the Iskenderpasa historical masonry minaret with an updated finite element model using operational modal testing. Soyluk and Tuna (2011) constituted a finite element model of Sehzade Mehmet mosque to determine its dynamic behaviour with seismic isolation. Bayraktar *et al.* (2012) presented a field investigation about performance of masonry buildings during the October 23 and November 9, 2011, Van Earthquakes. Can *et al.* (2012) practiced the seismic behaviour of historic masonry buildings with irregular geometry. Brandonisio *et al.* (2013) studied the seismic behaviour of four masonry churches in Italy damaged during the 2009 L'Aquila earthquake. Lucibello *et al.* (2013) investigated the seismic damage and performance of Palazzo Centi after L'Aquila earthquake and assessed the effectiveness of mechanical steel ties. Parisi and Augenti (2013) discussed the earthquake damages and seismic response of masonry structures. Bayraktar *et al.* (2014) investigated the damages of the reinforced concrete and masonry minarets during October 23 and November 9, 2011 Van earthquakes. Dal Cin and Russo (2014) searched the answers how annex influenced the seismic behaviour of Gesù historical church and how asymmetric mass can influence the behaviour of historical churches. Saisi and Gentile (2015) evaluated the post-earthquake condition of masonry Gabbia Tower in Italy with extensive experimental programme including geometric survey, visual inspections, ambient vibration tests, sonic and flat-jack tests. Saisi *et al.* (2015) installed a simple continuous dynamic monitoring system and examined the response of Gabbia tower under changing of environment conditions with expected sequence of far-field earthquakes. It can be seen from the literature that there is no enough studies about the seismic behaviour of mosques before and after restoration.

2. Seismic hazard of the Van region

Turkey, with intensive earthquake history, is located on the active seismic zone between the Arabian, Eurasian and African plates (Fig. 1). Many destructive earthquakes occurred during last two decades. Thousands of people died and millions of structures such as buildings, bridges, towers, mosques etc. were collapsed or heavily damaged.

As seen in Fig. 1, eastern part of Turkey has active seismic faults such as north and east Anatolians and many movements have been measured at this region by Kandilli Observatory and Earthquake Research Institute (KOERI 2011). Table 1 summarize the big earthquakes occurred in this region and around between 1903 and 2000.

Two big and destructive earthquakes occurred in Van, Turkey. The first earthquake with the magnitude of M_L=6.7 and M_w=7.2 occurred at local time 13:41 on Sunday, October 23, 2011 in Erciş township. The second earthquake with the magnitude of M_w=5.6 occurred at local time 21:23 on Wednesday, November 9, 2011 in Edremit township. With respect to the latest information data (December 9, 2011), a total of 6284 aftershocks occurred after October 23 and November 9, 2011 earthquakes between 1.7 and 5.8 magnitude. These earthquakes caused big destruction because of the presence of large amounts of masonry structures and the buildings which were constructed without considering the Specification for Buildings to be Built in Seismic Zones (TEC 2007).

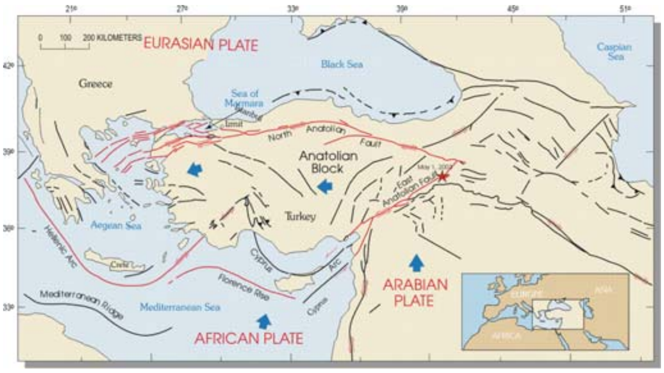


Fig. 1 Tectonic map of Turkey (USGS 2015)

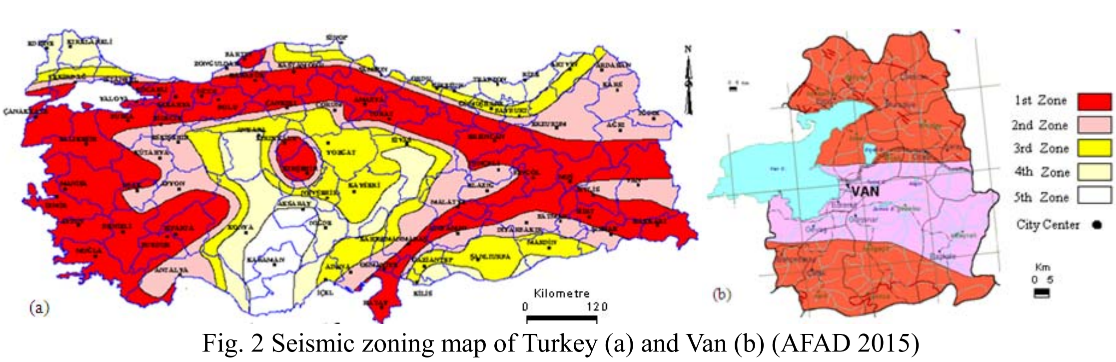


Fig. 2 Seismic zoning map of Turkey (a) and Van (b) (AFAD 2015)

Table 1 The big and destructive earthquakes occurred in Van and around between 1903 and 2000

Date (D/M/Y)	Time	Region	Magnitude (M)	Latitude (N)	Longitude (E)
28/04/1903	*23:39*	*Malazgirt*	*6.3*	*39.14*	*42.65*
06/05/1930	*22:34*	*Salmas*	*7.2*	*38.22*	*44.66*
10/09/1941	*21:53*	*Erciş*	*5.9*	*39.45*	*43.32*
20/11/1945	*06:27*	*Van*	*5.2*	*38.63*	*43.33*
25/06/1964	*00:11*	*Erciş*	*5.3*	*39.13*	*43.19*
24/11/1976	*22:15*	*Çaldıran*	*7.2*	*39.05*	*44.03*
17/01/1977	*19:24*	*Erciş*	*5.1*	*39.27*	*43.70*
25/06/1988	*15:38*	*Van*	*5.0*	*38.50*	*43.07*
15/11/2000	*05:34*	*Van*	*5.7*	*38.51*	*43.01*

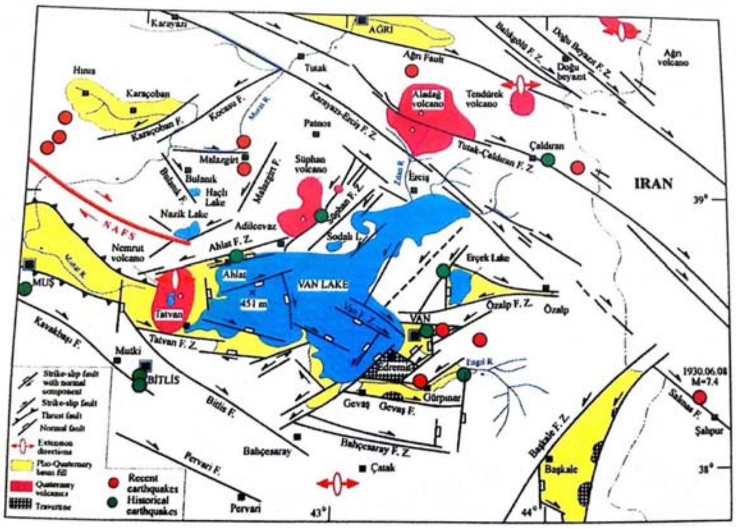


Fig. 3 The regional active fault map of Van (KOERI 2011)

According to the Seismic Zone Map, which is published by the Ministry of Public Works and Settlement of Turkey in 1996, the whole country is divided into five (5) seismic zones considering the maximum earthquake acceleration (Fig. 2(a)). It can be seen from this figure that big part of the Van city located at the first degree and the other regions located at the second degree earthquake zone (Fig. 2(b)) (AFAD 2015). The regional active fault map of Van is shown in Fig. 3.

3. Kaya Çelebi Mosque

Kaya Çelebi Mosque is located on the Orta Kapı district in Van, Turkey. The construction date of the mosque is not known exactly, but according to some sources, the mosque construction had been started by Kaya Çelebizade Koçi Bey in 1660 and had been finished by Cem Dedemoğlu Mehmet Bey in 1663.

The mosque, which is settled on 16.20 m×16.20 m square area, has one dome with 7.50 m radius and one minaret with 27.50 m height. The prayer place is surrounded with 1.8 m thickness walls and dome seats on eight arches. The minaret located on the north western region. Different material characterization can be found in the mosque. The dome consists of cut stone and brick, the side walls consist of cut and artless stone, arches and minaret consist of cut stone, respectively.

Kaya Çelebi Mosque was repaired in 1993 for opening the devotion. After, the restorations were carried out to strengthen the structural system between 2007 and 2011. A some view of the restored mosque is shown in Fig. 4.

Kaya Çelebi Mosque was heavily damaged at 23 October and 9 November 2011 Van earthquakes. The cone part of the minaret and the dome of the mosque collapsed. Some views of the mosque after two destructive earthquakes are shown Fig. 5.

Fig. 4 Kaya Çelebi Mosque (URL-1)

Fig. 5 Some views of the mosque after two destructive earthquakes

After the 23 October and 9 November 2011 Van earthquakes, it is observed some deterioration which affects the structural system of the mosque severely such as (see Fig. 6);

- Cracks
- Material deformation and deterioration
- Joints debonding
- Rupture, dislocation, decomposition of stones
- Environmental condition effect such as humidity, age, temperature, vegetation

After two destructive earthquakes, the mosque was closed to worship. The restoration process has still continued, and the mosque has been planned to open in five months. Some views of the restoration project can be shown in Fig. 7. Different parts of the structure are described by introducing plan and elevation drawings. Also, characteristics of the different materials adopted in the different parts of the mosque can be seen.

Fig. 6 Some views of the deteriorations

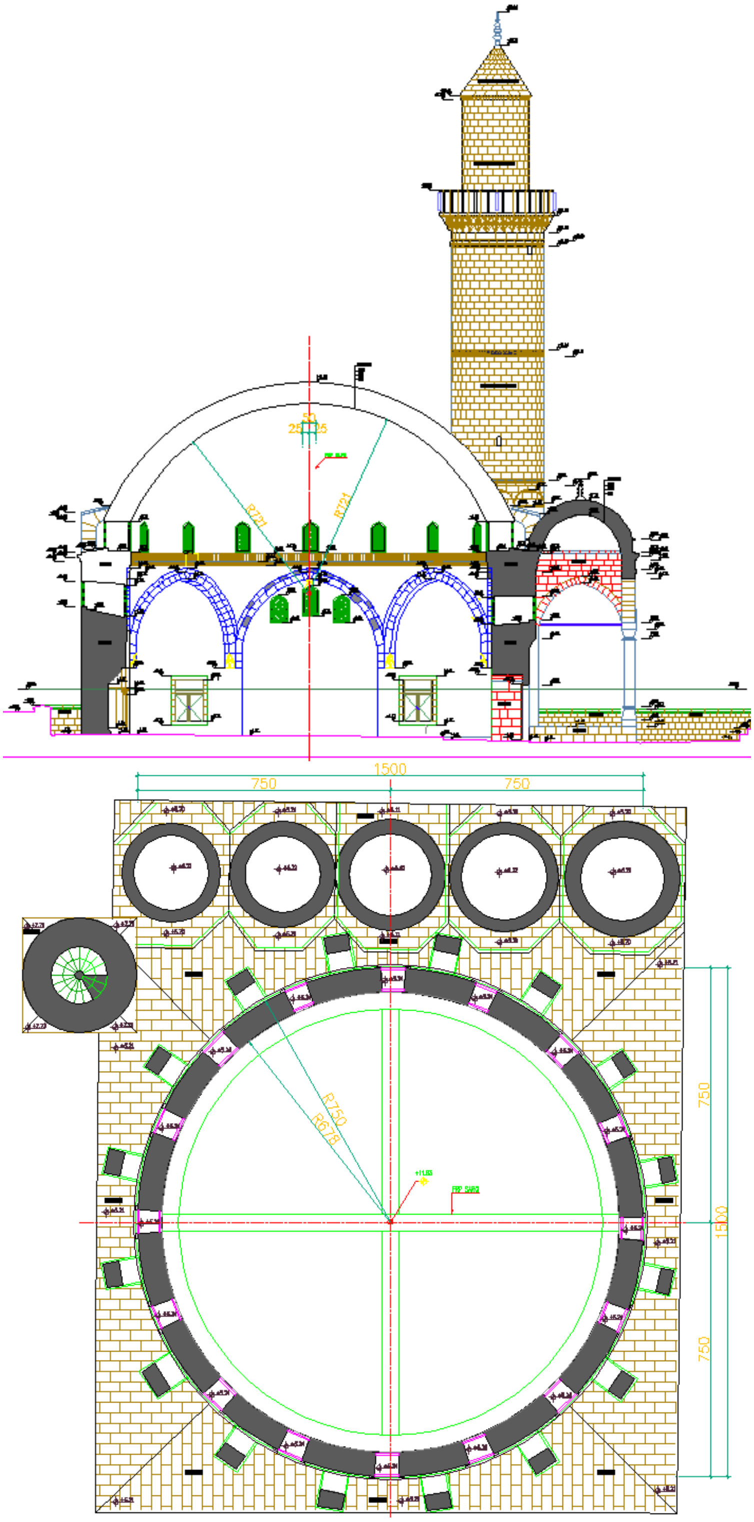


Fig. 7 Some views of the restoration project

4. Finite element analyses

Finite element model of Kaya Çelebi Mosque are constituted using restoration drawings in SAP2000 software (SAP2000 2015). General information, structural dimensions and material properties are taken from restoration project, calculation and art history reports. The finite element model of the mosque consist of two nodes bar, four nodes area and twelve nodes 3D solid elements. Each node has three degrees of freedom: translations in the nodal x, y, and z directions. The model has 29567 nodes, 270 bar elements, 27123 area elements and 108585 3D solid elements (Fig. 8).

To determine the structural response of the mosques, some load cases are considered as:

- *Modal analysis of mosque*
- *Earthquake analysis considering mode superposition method (x, y and z direction)*

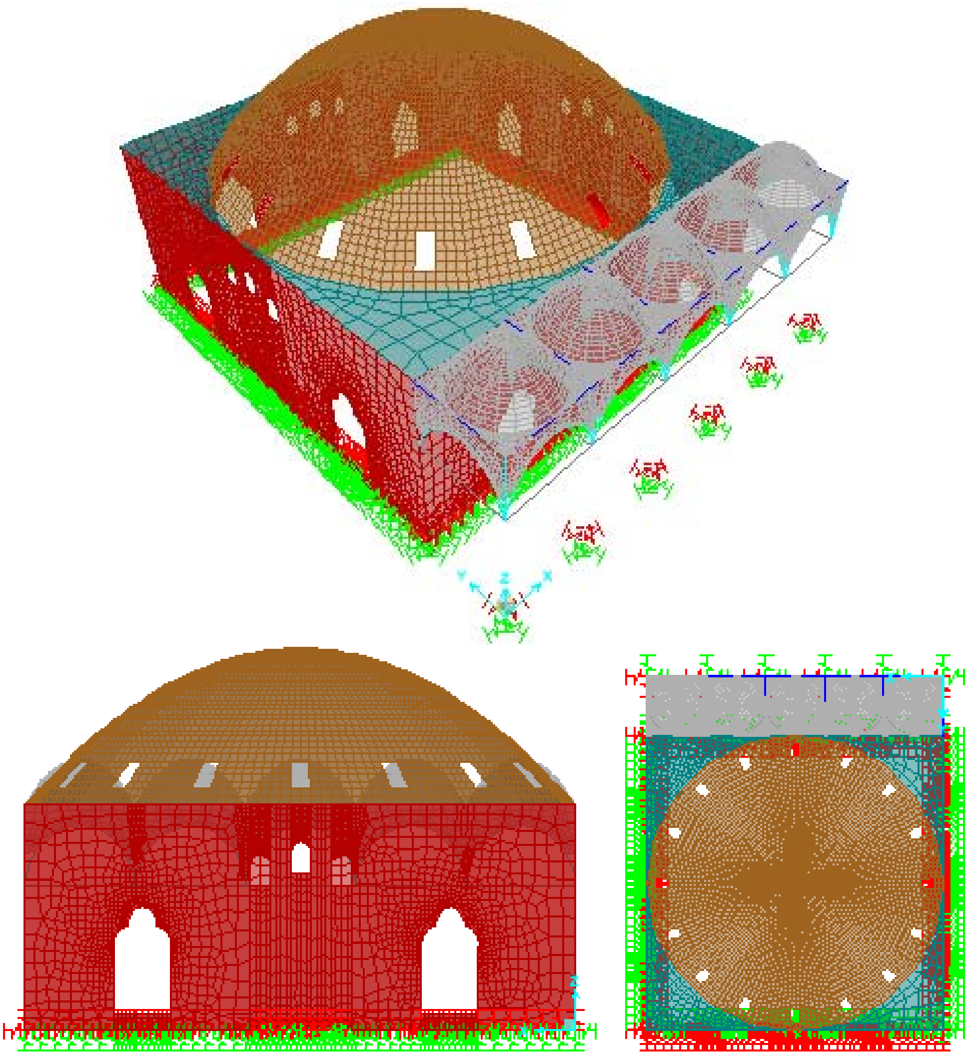


Fig. 8 Finite element model of Kaya Çelebi Mosque

Table 2 Material properties considered in the analyses

Structural System Components	**Material Properties**		
	Young's modulus (N/m²)	*Poisson's ratio (-)*	*Density (kg/m³)*
Location of worship			
Cut Stones	1.60E09	0.200	2000
Artless Stone (*with considering the mortar*)	4.50E08	0.200	2400
Brick	1.20E09	0.200	2400
Outer Part of Worship Location			
Cut Stones	1.60E09	0.200	2000
Marble	3.54E10	0.316	2690
Stretcher	2.00E11	0.300	7850

Structural performances of historical structures built using brick and stone masonry cannot be evaluated accurately with linear elastic analysis methods. Nonlinear analyses can give exact results if detailed material properties of masonry are correctly defined. But nonlinear analysis method caused some problem at iterations when structures considered have very big and complex geometry. In addition, defining the material properties of non-homogeneous structures like masonry structures is fairly difficult. Due to these issues, linear elastic analyses were performed.

In this study, the selected material properties are given in Table 2 (Can *et al*. 2012, Dal Cin and Russo 2014, Saloustros *et al*. 2015).

Seismic analysis is performed using the response spectrum with mode superposition method. Complete Quadratic Combination (CQC) method is used to modal combination. This approach assumes that the maximum modal values, for all modes, occur at the same point in time.

In the analyses, the spectral acceleration coefficient $S(T)$ is taken as 2.5 and the effective earthquake coefficient (A_o) is chosen as 0.3. The load reduction coefficient (R_a) is selected as 1.0 in each period. Also, the safety stresses are increased triple.

2007 Turkish Earthquake Code - Chapter 5.3 (pressure safety stresses of walls in which free pressure strength is unknown) (TEC 2007) is taken into consideration to compare the finite element analysis results with the code limits. The compression values of masonry stones and brick walls are selected as 0.3 MPa and 0.8 MPa from the code, respectively. The compression safety stresses for brick and stone materials calculated as

f_s=0.8×3=2.4 MPa (Brick used in dome)
f_s=0.3×3=0.9 MPa (Stone used in walls and arches)

The tensile safety stresses are accepted as 15% of the compression safety stresses, thus we have

f_s=2.4×0.15=0.36 MPa (Brick used in dome)
f_s=0.9×0.15=0.135 MPa (Stone used in walls and arches)

The shear stresses obtained from the finite element analyses are compared with the shear safety stresses (τ_s) which are calculated according to following equation

$$\tau_s=\tau o+\mu\sigma$$

Table 3 Safety stresses of materials

Materials	Material Properties		
	Pressure Safety Stresses (MPa)	*Tension Safety Stresses (MPa)*	*Shear Safety Stresses (MPa)*
Brick	2.40	0.360	1.05
Stonewall	0.90	0.135	0.53
Arches	0.90	0.135	0.53

In this equation; τ_s=shear safety stress of the wall, τ_o=safety stress of the wall cracking, μ=coefficient of friction (taken as 0.5) and σ=vertical stresses of the wall.

The safety stress of the wall cracking is calculated below for stone and brick as

τ_o=0.15×3=0.45 MPa (Brick used in dome)
τ_o=0.10×3=0.30 MPa (Stone used in walls and arches)

The shear safety stresses of brick and stones are calculated as

τ_s=0.45+0.5(2.4/2)=1.05 MPa (Brick used in dome)
τ_s=0.30+0.5(0.9/2)=0.53 MPa (Stone used in walls and arches)

Safety stresses for materials which are used in Kaya Çelebi Mosque are given in Table 3.

4.1. Modal analysis

The dynamic characteristics such as natural frequencies and mode shapes are obtained from modal analyses of Kaya Çelebi Mosque. The first four natural frequencies are obtained between 3.79 Hz and 6.02 Hz. The mode shapes are given in Fig. 9. As seen from the figure that the first and second modes are translational modes in x and y directions, respectively. The third mode is torsional mode with 5.48 Hz. The fourth mode is obtained similar to the first and second modes with 6.02 Hz.

4.2. Seismic analysis

Seismic analysis is performed using the response spectrum applying the lateral direction (x) with the mode superposition method. Complete Quadratic Combination (CQC) method is used to modal combination and dead loads are calculated by the program automatically. The maximum displacements, tensile, compression and shear stresses are obtained from the analyses.

The maximum displacements contour diagram of the mosque is shown in Fig. 10. It is seen that the displacements have an increasing trend from the bottom to upper part of side walls, and towards to central point of the dome. The maximum displacements are obtained as 36.4 mm at the central point of the dome.

The maximum tensile stresses contour diagram of the mosque is shown in Figs. 11(a)-(b) for outer and inner surfaces, respectively. It is seen from the Fig. 11 that maximum tensile stresses for outer surface occurred at side part of the dome and near the window spaces as 0.75 MPa. For inner surface, maximum tensile stresses are 0.85 MPa.

The maximum compressive stresses contour diagram of the mosque is shown in Figs. 12 (a)-(b) for outer and inner surfaces, respectively. It is seen from the Fig. 12 that maximum compressive stresses for outer surface occurred at the dome and side wall intersection points as 1.65 MPa. Also, some stress intensity regions are obtained at the window spaces. For inner surface, maximum compression stresses are 1.45 MPa.

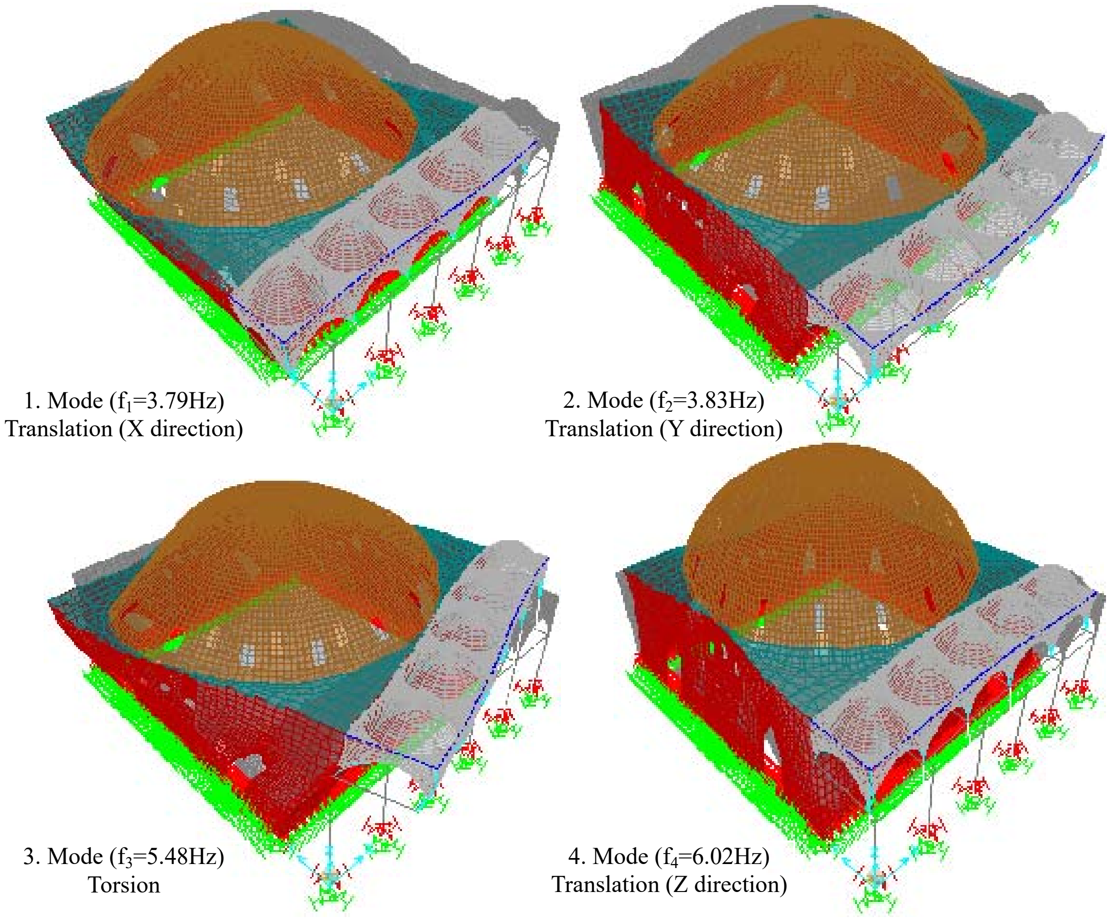


Fig. 9 The first four mode shape and related the frequencies

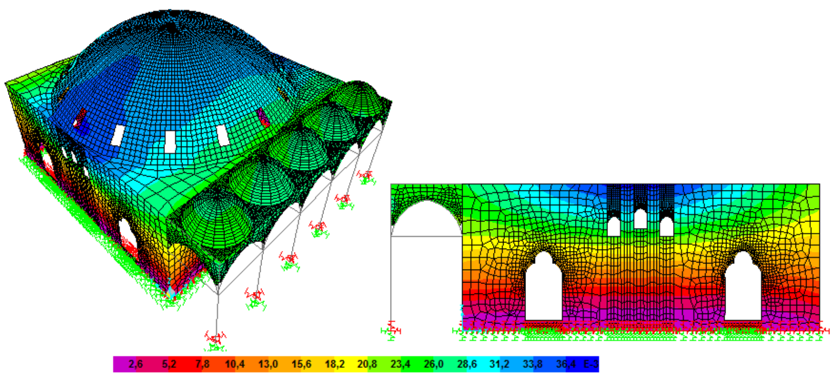
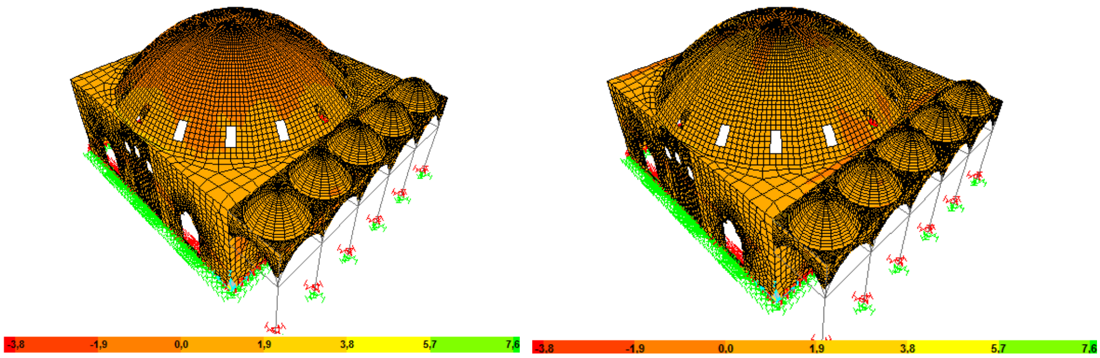
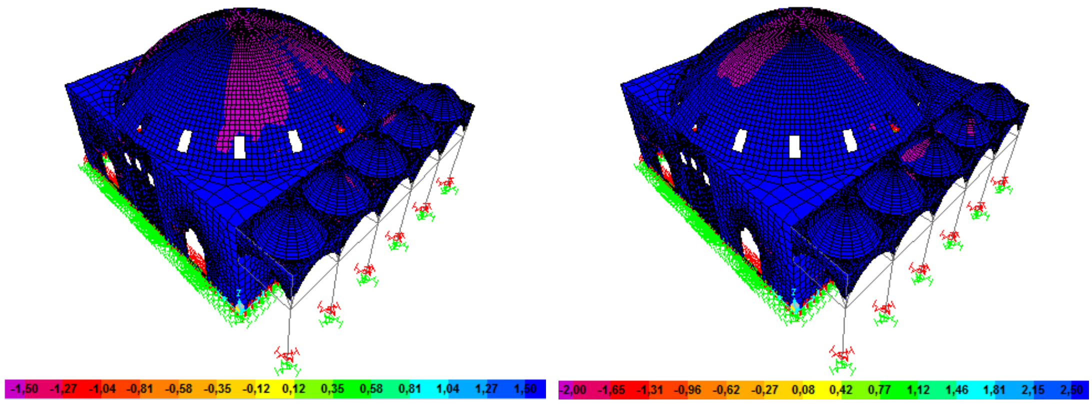


Fig. 10 Maximum displacements contour diagram



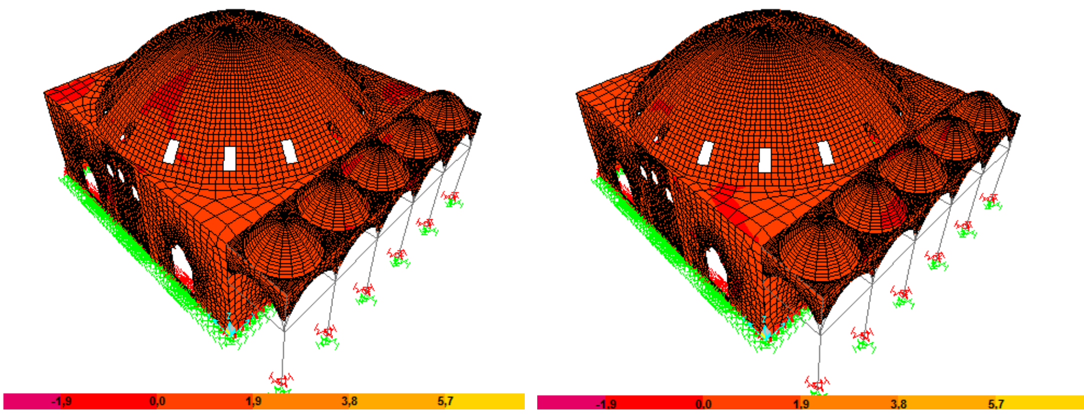
(a) (b)

Fig. 11 Maximum tensile stresses contour diagram for outer (a) and inner (b) surfaces



(a) (b)

Fig. 12 Maximum compression stresses contour diagram for outer (a) and inner (b) surfaces



(a) (b)

Fig. 13 Maximum shear stresses contour diagram for outer (a) and inner (b) surfaces

The maximum shear stresses contour diagram of the mosque is shown in Figs. 13 (a)-(b) for outer and inner surfaces, respectively. It can be seen from the Fig. 13 that maximum shear stresses

Table 4 Analysis results

Analyses Data			**Spectrum Analyses**		
			(X direction)	*(Y direction)*	*(Z direction)*
Displacement(mm)			36.4	35.0	15.4
Stresses (MPa)	Comp.	*Outer*	1.65	1.50	1.05
		Inner	1.45	1.25	0.85
	Tension	*Outer*	0.75	0.80	0.60
		Inner	0.85	0.65	0.45
	Shear	*Outer*	0.50	0.50	0.30
		Inner	0.40	0.35	0.20

are obtained as 0.50 MPa and 0.40 MPa for outer and inner surfaces, respectively.

The response spectrum analyses given in the above is performed only lateral (x) direction. To obtain the mosque response more accurately, the analyses are repeated for all directions separately such as y and z. The contour diagrams of this analysis results are not presented here. However, the comparison of the results are presented in Table 4.

It can be seen from Table 4 that lateral displacements (x and y direction) are obtained nearly similar to each other. Because, the mosque has similar rigidity at both sides. Only, outer part of the worship on y direction effect this changes. 3.8% differences is obtained. In addition, vertical displacements are quite different from the others. Vertical displacements (15.4 mm) are calculated as nearly half of lateral displacements. It can be said that the dome has an enough rigidity and stability for dynamic loads.

When the compressive stresses are compared with each other for outer and inner regions, it is seen that the values are nearly equal. The outer compressive stresses are obtained between 1.65 MPa and 1.50 MPa for lateral direction. But, these values are decreased nearly 36% with spectral acceleration applied in vertical direction. Same distributions are found for inner compression stresses.

When the tensile stresses are compared with each other for outer and inner regions, it is seen that the values are nearly equal. The outer tensile stresses are obtained between 0.75 MPa and 0.80 MPa for lateral direction. But, these values decrease nearly 25% with spectral acceleration applied in vertical direction. Same distributions are obtained for inner compressive stresses. The values of compressive stresses are bigger than tensile stresses nearly about 47%.

When the shear stresses are compared with each other for outer and inner regions, it is seen that the values are nearly equal. The outer shear stresses are obtained between 0.50 MPa and 0.40 MPa for lateral direction. But, these values decrease nearly 40% with spectral acceleration applied in vertical direction. Same distributions are obtained for inner compressive stresses. The values of shear stresses are lower than the compressive and tensile stresses.

5. Conclusions

The aim of this study is to investigate the seismic response of historical masonry mosque after restoration. Finite element model of Kaya Çelebi Mosque are constituted using restoration drawings in SAP2000 software. Seismic analysis is performed using the response spectrum with the mode superposition method. CQC method is used to modal combination. As a result of the study, the following observations were made:

• To determine the structural response of the mosques, four different analyses are performed. Firstly the dynamic modal analysis, and subsequently the seismic spectral analysis are performed in *x*, *y* and *z* directions using the finite element model.

• The dynamic characteristics such as natural frequencies and mode shapes are obtained from modal analyses. The first four natural frequencies are obtained between 3.79 Hz and 6.02 Hz. The first and second modes are translational modes in *x* and *y* directions, respectively. The third mode is torsional with 5.48 Hz. The fourth mode shapes is obtained as similar to first and second mode shapes with 6.02 Hz.

• The displacements have an increasing trend from the bottom to upper part of side walls, and towards to central point of the dome. The maximum displacements are obtained as 36.4 mm at the central point of the dome. The maximum relative displacement is calculated approximately 0.003. This value remains within acceptable limits.

• The maximum tensile stresses for outer surface occurred at side part of the dome and near the window spaces as 0.75 MPa. For inner surface, maximum tensile stresses are obtained as 0.85 MPa.

• The maximum compressiove stresses for outer surface are occurred at the dome and side wall intersection points as 1.65 MPa. Also, some stress intensity regions are obtained at the window spaces. For inner surface, maximum compressive stresses are obtained as 1.45 MPa.

• The maximum shear stresses are obtained as 0.50MPa and 0.40MPa for outer and inner surfaces, respectively.

• The lateral displacements (x and y direction) are obtained nearly similar to each other. Because, the mosque has similar rigidity at both sides. Only, last caboodle region on y direction effects these changes. 3.8% difference is obtained. In addition, vertical displacements are quite different from the others. Vertical displacements (15.4 mm) are calculated as nearly half of lateral displacements. It can be said that the dome has an enough rigidity and stability for dynamic loads.

• When the compressive stresses are compared with each other for outer and inner regions, it is seen that the values are nearly equal. The outer compression stresses are obtained 1.65 MPa and 1.50 MPa for lateral direction. But, these values decrease nearly 36% with spectral acceleration applied in vertical direction. Same findings are obtained for inner compressive stresses.

• When the tensile stresses are compared with each other for outer and inner regions, it is seen that the values are nearly equal. The outer tensile stresses are obtained between 0.75 MPa and 0.80 MPa for lateral direction. But, these values decrease nearly 25% with spectral acceleration applied in vertical direction. Same findings are obtained for inner compressive stresses. The values of compressive stresses are bigger than tensile stresses nearly about 47%.

• When the shear stresses are compared with each other for outer and inner regions, it is seen that the values are nearly equal. The outer shear stresses are obtained between 0.50 MPa and 0.40 MPa for lateral direction. But, these values decrease nearly 40% with vertical direction spectral acceleration. Same distributions are obtained for inner compressive stresses. The values of shear stresses are lower than the compressive and tensile stresses.

• It is seen from the analyses that the compressive and shear stresses do not exceed the allowable values presented in Turkish Earthquake Code.

• Tension stresses are occurred locally at near the spaces, bottom of the walls and some areas in which big dome seats the side walls. The values obtained are within the allowable level for dynamic loads.

• Compressive, tension and shear stresses occured above the limit values at some critic locations such as near side of the window/door spaces and elements intersection points. These regions should be constructed as monolithic during restoration.

Since historical masonry structures are our cultural heritage, it is essential to strengthen them and confidently transfer to the future. So, the restoration studies have become more importance during last two decades. Before the restoration, structural performance of the structures under dynamic loads (lateral and vertical directions) should be accurately determined and the related suggestions should be made to obtain enough stability with restoration.

References

AFAD (2015), Earthquake Department of the Disaster and Emergency Management Presidency, Ankara, Turkey, http://www.afad.gov.tr/.

Akan, A.E. (2010), "Determination of structural performance of timber pillared historical mosques by finite element analysis", *SDU Int. Technologic Sci.*, **2**(1), 41-54.

Bayraktar, A., Coşkun, N. and Yalçin, A. (2007), "Performance of masonry stone buildings during the March 25 and 28, 2004 Aşkale (Erzurum) earthquakes in Turkey", *J. Perform. Constr. Facil.*, **21**(6), 432-440.

Bayraktar, A., Altunişik, A.C., Sevim, B. and Türker, T. (2010), "Seismic response of a historical masonry minaret using a finite element model updated with operational modal testing", *J. Vib. Control*, **17**(1), 129-149.

Bayraktar, A., Altunışık, A.C. and Muvafık, M. (2012), "Field investigation of the performance of masonry buildings during the October 23 and November 9, 2011, Van Earthquakes in Turkey", *J. Perform. Constr. Facil.*, doi: 10.1061/(ASCE)CF.1943-5509.0000383.

Bayraktar, A., Altunışık, A.C. and Muvafık, M. (2014), "Damages of minarets during Erciş and Edremit Earthquakes, 2011 in Turkey", *Smart Struct. Syst.*, **14**(3), 479-499.

Brandonisio, G., Lucibello, G., Mele, E. and De Luca, A. (2013), "Damage and performance evaluation of masonry churches in the 2009 L'Aquila earthquake", *Eng. Fail. Anal.*, **34**, 693-714.

Can, H., Joseph, K. and Unay, A.İ. (2012), "Seismic behaviour of historical masonry buildings with irregular geometry", *J. Fac. Eng. Arch. Gazi Univ.*, **27**(3), 679-686.

Dal Cin, A. and Russo, S. (2014), "Influence of the annex on seismic behavior of historic churches", *Eng. Fail. Anal.*, **45**, 300-313.

Lourenço, P.B. and Roque, J.A. (2006), "Simplified indexes for the seismic vulnerability of ancient masonry buildings", *Constr. Build. Mater.*, **20**(4), 200-208.

Lucibello, G., Brandonisio, G., Mele, E. and De Luca, A. (2013), "Seismic damage and performance of Palazzo Centi after L'Aquila earthquake: A paradigmatic case study of effectiveness of mechanical steel ties", *Eng. Fail. Anal.*, **34**, 407-430.

KOERI (2011), Kandilli Observatory and Earthquake Research Institute, *Preliminary Report, The November 09, 2011 Edremit-Van, Turkey Earthquake (ML=5.6)*, Department of Earthquake Engineering, Bogazici University, Istanbul, Turkey.

Paret, T.F., Freeman, S.A., Searer, G.R., Hachem, M. and Gilmartin, U.M. (2008), "Using traditional and innovative approaches in the seismic evaluation and strengthening of a historic unreinforced masonry synagogue", *Eng. Struct.*, **30**(8), 2114-2126.

Parisi, F. and Augenti, C. (2013), "Earthquake damages to cultural heritage constructions and simplified assessment of artworks", *Eng. Fail. Anal.*, **34**, 735-760.

Saisi, A. and Gentile, C. (2015), "Post-earthquake diagnostic investigation of a historic masonry tower", *J. Cultural Herit.*, **16**(4), 602-609.

Saisi, A., Gentile, C. and Guidobaldi, M. (2015), "Post-earthquake continuous dynamic monitoring of the

Gabbia Tower in Mantua, Italy", *Constr. Build. Mater.*, **81**, 101-112.
SAP2000 (2015), Computers and Structures Inc. Berkeley, California, USA.
Saloustros, S., Pelà, L., Roca, P. and Portal, J. (2015), "Numerical analysis of structural damage in the church of the Poblet Monastery", *Eng. Fail. Anal.*, **48**, 41-61.
Soyluk, A. and Tuna, M.E. (2011), "Dynamic analysis of historical Şehzade Mehmet mosque for base isolation application", *J. Fac. Eng. Arch. Gazi Univ*., **26**(3), 667-675.
TEC (2007), *Specification for Buildings to be Built in Seismic Zones*, Ministry of Public Works and Settlement, General Directorate of Disaster Affairs, Earthquake Research Department, Ankara, Turkey, http://www.deprem.gov.tr.
URL-1 (2015), http://ankarafotosafari.blogspot.com.tr/.
USGS (2015), *U.S. Geological Survey, Tectonic Map of Turkey*, (http://earthquake.usgs.gov/earthquakes/eqarchives/year/2003/2003_05_01_maps.php, 27 June 2015).

CC