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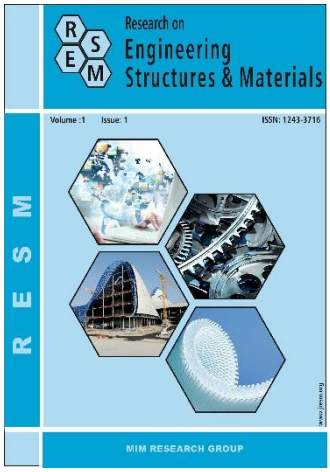

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Online Publication Date: 8 Dec 2016
URL: http://dx.doi.org/10.17515/resm2016.82st0728.html
DOI: http://dx.doi.org/10.17515/resm2016.82st0728

Journal Abbreviation: *Res. Eng. Struct. Mat.*

To cite this article
Calik I, Bayraktar A, Türker T, Ayan AO. Dynamic identification of historical Molla Siyah mosque before and after restoration. *Res. Eng. Struct. Mat.*, 2017; 3(3): 164-175.

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Research Article

Dynamic identification of historical Molla Siyah mosque before and after restoration

İsmet Çalık*[1], Alemdar Bayraktar[2], Temel Türker[2], Ali Osman Ayan[1]

[1]*Directorate General of Foundations, Trabzon Regional Directorate, 61080, Trabzon, Turkey*
[2]*Karadeniz Technical University, Department of Civil Engineering, 61080, Trabzon, Turkey*

Article Info

Article history:
Received 28 Jul 2016
Revised 28 Now 2016
Accepted 4 Dec 2016

Keywords:
Restoration Effects, Ambient Vibration Testing, Experimental Dynamic Characteristics, Historical Mosques, Molla Siyah Mosque, Masonry Structures

Abstract

The effects of restoration on the experimental dynamic characteristics of historical masonry Molla Siyah Mosque in Trabzon, Turkey, are investigated in this paper. Firstly, the initial situation and the implemented restoration works of the mosque are mentioned in detail. Then, the experimental dynamic behaviors of the mosque before and after the restoration are obtained by using the Ambient Vibration Tests. High sensitivity seismic accelerometers with cables are used during the tests. The collected signals are evaluated by Enhanced Frequency Domain Decomposition Technique, and experimental natural frequencies, mode shapes and damping ratios of the mosque are determined for the initial and restoration cases. The obtained results are compared with each other and restoration effects on the dynamic behavior of the mosque are discussed in detail.

1. Introduction

The historical structures are very important for humanity because they link the past to the future. These structures have been exposed to the natural disasters and human interventions. In many case, these interventions created irreversible damage on the historical structures. Therefore, the restorations were required to transfer the historical structures to the next generation in original case. The restoration projects were prepared by using modern technology and more scientific data. However, it is not given required attention to the effects of the restoration on the static and dynamic behaviors of the historical structures.

Many studies on the analytical and experimental behaviors of the historical structures have been implemented. Turek et al. [1] carried out the experimental test of the church named as La Iglesia de la Compañía de Jesus in the South America. Durukal et al. [2] evaluated the change in the dynamic behavior of Ayasofya and Sultanahmet Mosques after the Düzce and Kocaeli eartquakes. Bayraktar et al. [3-4] identified the dynamic characteristics of historical structures. Aras et al. [5] determined the experimental and analytical modal parameters of a historical masonry palace built in İstanbul. Atamturktur et al. [6] vibration characteristics of vaulted masonry monuments undergoing differential support settlement. Some studies were performed by Lourenço and Ramos [7], Atamturktur and Laman [8], Can and Ünay [9], Tashkov et al. [10] and Bayraktar et al. [11]. Çalık et al. [12] investigated the historical masonry minarets by experimental and analytical methods. The restoration effects on the dynamic behavior of many historical structures were investigated by Çalık et al. [13-15]. Bayülke et al. [16] investigated the

*Correspondingauthor: ismetcalik@yahoo.com
DOI: http://dx.doi.org/10.17515/resm2016.82st0728

dynamic behavior of many mosques damaged on the 2011 Simav Earthquake in Turkey. Foti et al. [17] was presented the results of an ambient-vibration based investigation conducted on a historical tower in Italy, to update the 3-D finite element model of the building. It was observed that a very good match between theoretical and experimental modal parameters was reached and the model updating has been performed to identify some structural parameters. Dynamic identification techniques for the non-destructive evaluation of heritage structures were presented by Rainieri et al. [18]. In this paper, the importance of the updating parameters and of the objective function selection was introduced. Also it was described the refinement of the model in a way able to minimize the scatter with the experimental. The dynamic identification of a historical masonry palace located in Benevento (Italy) has been carried out by Ceroni et al. [19]. The case study is representative of many buildings located in historic Italian centres. A permanent dynamic monitoring system was used to recorded data and they were analysed with basic instruments of the Operational Modal Analysis in order to identify the main dynamic characteristics.

It was observed that the success of a restoration project highly depends on the good identification of in-situ behavior. Therefore, the effect of the restoration on the static and dynamic behavior of the historical structures should be investigated experimentally. In this study, the dynamic characteristics of Ortahisar MollaSiyah Mosque in Trabzon, Turkey, were determined by experimental modal analysis method before and after restoration, and the effects of the restoration were evaluated by comparing the dynamic characteristics.

2. Brief Description of Molla Siyah Mosque

The MollaSiyah Mosque is located in Ortahisar Pazarkapı neighborhood on block 100 in parcel 7, Trabzon, Turkey. Its ownership belongs to the Fatih Sultan Mehmet Foundation. The place of the mosque is presented in Fig. 1.

Fig. 1. MollaSiyah Mosque, Ortahisar, Trabzon, Turkey [20]

The structure of the mosque was built as a church in the XI Century initially. It was converted into a mosque before the 1557 [21]. The owner of the structure is Foundation of Fatih Sultan Mehmet, the administration and the representation is carried out by the General Directorate of Foundations. The mosque was restored and strengthened by the Trabzon Regional Directorate of Foundations in 2015. The photographs of the mosque before and after restoration are presented in Fig. 2.

Fig. 2. Images of Trabzon MollaSiyah Mosque before and after the restoration

The original structure was made of rubble stone with about 70cm wall depth as usual architectural church plan. There are 4 main columns in the middle of the structure. The structure has been seen interventions at different times to the present day. There is a concrete cover on the domes and vaults were constructed in early restorations. Fig. 3 provides images of the layout, inside and outside of the survey project, and Fig. 4 shows images of the layout, inside and outside of the restoration project of MollaSiyah Mosque. The artifact is presently open for worship and is actively being used.

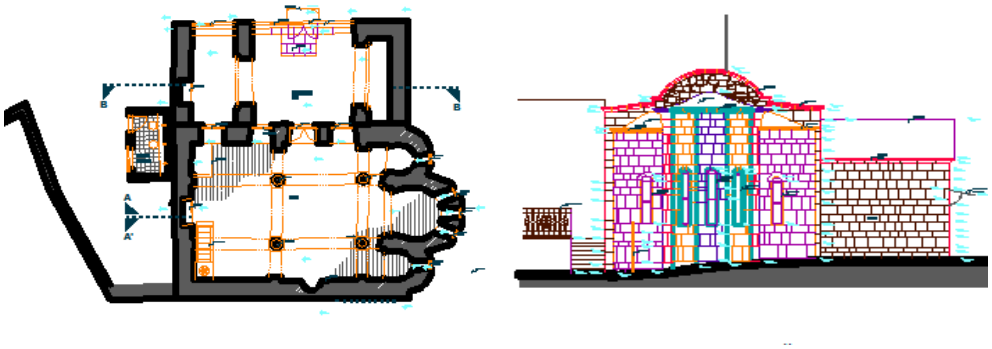


Fig. 3. Layout, inside and outside of the survey project of Molla Siyah Mosque [22]

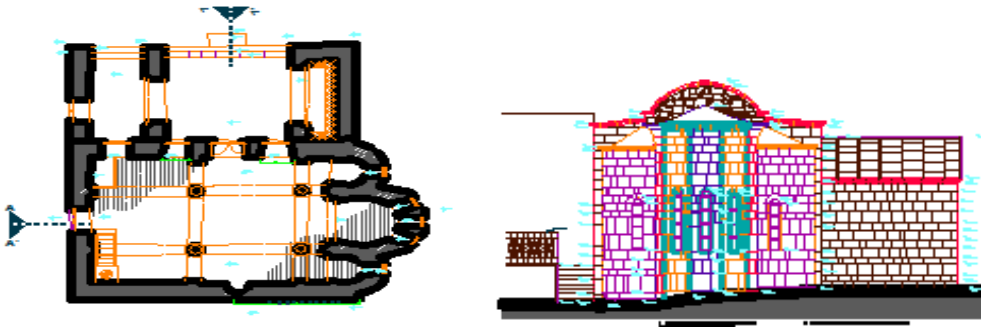


Fig. 4. Layout, inside and outside of the restoration project of Molla Siyah Mosque [23]

3. Restoration Applications of MollaSiyah Mosque

Within the scope of restoration works, the following interventions were made.

- The attachment narthex was demolished and the original narthex was brought forth.

Waterproofing was done at the roof and it was covered with the lead by traditional techniques.

- The stone altar was cleaned of oil paint and the original stone elements were revealed.
- The mosques interior plaster has been renovated with Horosan mortar.
- After dismantling of interior plaster, it was seen that there are some deep cracks on the east and west vaults of the narthex which are in line of north to south. The injection of hydraulic lime mortar and steel sewing techniques were used to strengthening of these structural elements (Fig. 5). Also at the southwest corner of the mosque, a crack was detected from the top to the bottom. This crack is also strengthened with same techniques (Fig. 5).

Fig. 5. Strengthening applications

- After dismantling of interior plaster, it was observed that the beams connecting the walls and columns were made of reinforced concrete. Therefore, the beams were not converted to the masonry. They were renovated with Horosan mortar (Fig. 6). The filler on the ground were removed and it was covered with wooden slab (Fig. 6).

Fig. 6. Wall, arch and excavation applications

- The rotten wood flooring and windows were refurbished.
- The outer facades of the mosque were stripped of mortar and joints are filled with Horosan mortar.
- Drainage and landscaping applications were done.
- The electrical fixtures were renovated and ambient lighting was completed. Also air conditioning fitted.

The images of MollaSiyah Mosque after the restoration are given in Fig. 7.

Fig. 7. The images of Molla Siyah Mosque after the restoration

4. Ambient Vibration Tests of Molla Siyah Mosque

The Ambient Vibration Tests is a method which is effective in the determination of dynamic characteristics of existing structures such as natural frequency, mode shape and damping ratio. Since no damage is created in the structure during measurements by this method, it is a useful and preferred method for historical structures. In this method, which is also called the Operational Modal Analyses, the dynamic behavior of the structure is measured under the ambient loads such as wind or pedestrian movements by using sensors.

The measurements on the mosque were done with the Ambient Vibration Test Method. B&K8340 type seismic accelerometers and a 17-channel B&K3560 data acquisition unit was used. The collected data was transferred to a computer using the PULSE [24]

software and the dynamic characteristics of the structure were obtained using OMA software [25].

Enhanced Frequency Domain Decomposition (EFDD) technique [23] was used to obtain the natural vibration frequencies, mode shapes and modal damping ratios of the mosque from the signals. . The main formulations of this method can be found in the literature [26-27].

4.1. Measurements before the restoration

A total of 12 accelerometers were used in the measurements performed on the Molla Siyah Mosque before and after the restoration. The accelerometers were attached to the corner points of the mosque in the transverse and longitudinal directions. The used accelerometers have 10V/g sensitivity and 0.1–1500 Hz frequency range. the excitation was turned on. The frequency range for the base measurement was selected 0–12.5 Hz according to the pretest results to get the first three modes of the building model and 1024 number of sampling point was also used in these measurements. The measurement durations were selected as 60 min. Some images of the accelerometer placements and the data acquisition system are given in Fig. 8.

Fig. 8. The images of measurements of Molla Siyah Mosque before the restoration

The representative model of the mosque and the accelerometer connection points and directions during the test is shown in Fig. 9.

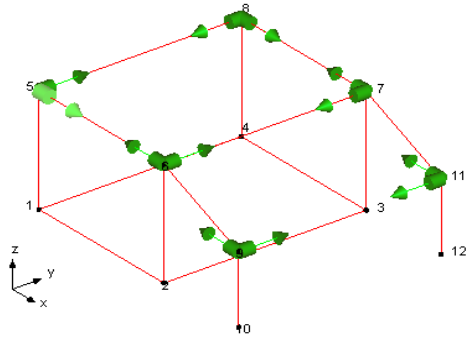


Fig. 9. A representative model of the accelerometer locations before the restoration

Measurements were taken from the outer body of the walls before the restoration for a period of 30 minutes and the resulting signals were analyzed using Enhanced Frequency

Domain Decomposition (EFDD) technique. The singular value plot obtained from the mosque before the restoration measurement as shown in Fig. 10.

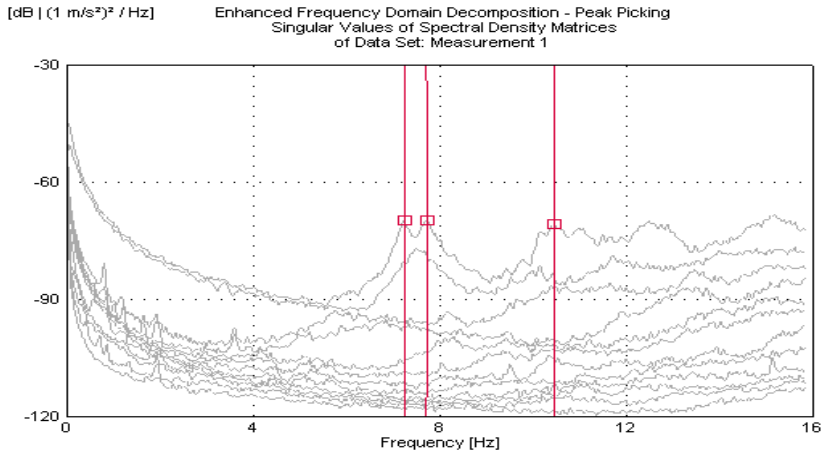
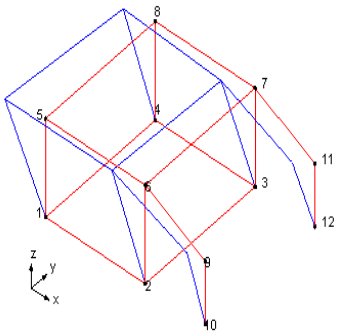
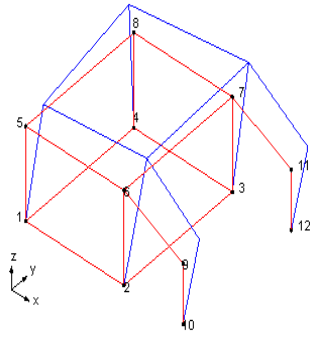


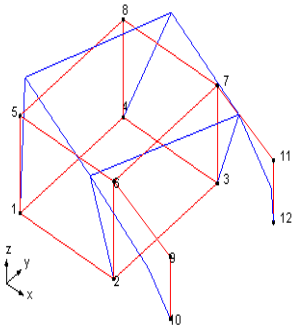
Fig. 10. The frequency response function obtained from the mosque before the restoration measurement



Mode 1 (7.249Hz)



Mode 2 (7.721Hz)



Mode 3 (10.480Hz)

Fig. 11. The first three mode shapes of Molla Siyah Mosque before the restoration

The first three natural frequencies and mode shapes before the restoration are shown in Fig. 11.

4.2. Measurements after the restoration

The same representative model of the accelerometer locations given in Fig.9 are used after the restoration. There are some images of the accelerometer placements and the data collection systems in Fig. 12.

Fig. 12. Some images of the measurements of Molla Siyah Mosque after the restoration

Measurements were taken from the outer body walls of the mosque after the restoration for a period of 30 minutes and the resulting signals were analyzed using the Enhanced Frequency Domain Decomposition (EFDD) technique. The singular value plot obtained from the mosque after the restoration measurement is given in Fig. 13.

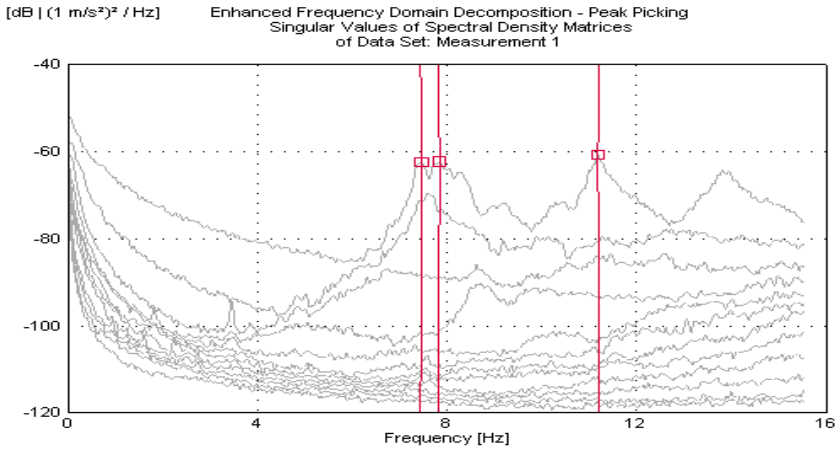
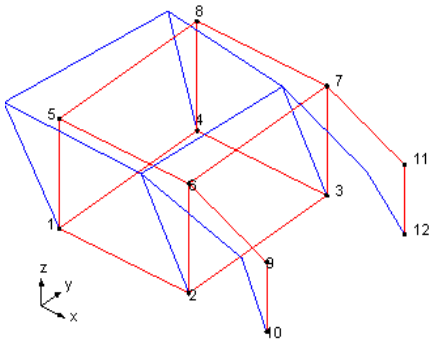
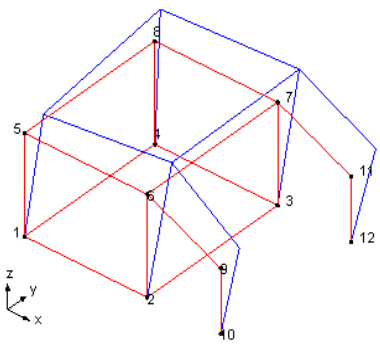


Fig. 13. The frequency response function obtained from the mosque after the restoration measurement

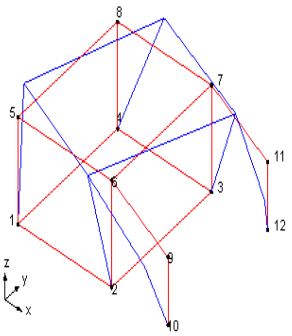
The first three natural frequencies and mode shapes after the restoration of the mosque are shown in Fig. 14.



Mode 1 (7.445Hz)



Mode 2 (7.831Hz)



Mode 3 (11.210Hz)

Fig. 14. The first three mode shapes of Molla Siyah Mosque after the restoration

4.3. Comparison and evaluation

The first three natural vibration frequencies of Molla Siyah Mosque before and after restoration are compared in Table 3. It can be seen from Table 3 that all frequencies slightly increase after the restoration. However, damping ratios decrease with the restoration. The first, second and third mode shapes of the mosque as shown in Fig. 11 and 14 occur in longitudinal, transverse and torsional directions, respectively, for both before and after restoration.

Table 3. The first three natural vibration frequencies and damping ratios of Molla Siyah Mosque before and after restoration

Mode Number	Before Restoration		After Restoration	
	Frequency (Hz)	Damping Ratio (%)	Frequency (Hz)	Damping Ratio (%)
1	7.249	1.520	7.445	1.172
2	7.721	1.378	7.831	1.467
3	10.480	2.582	11.210	2.089

5. Conclusions

The dynamic characteristics of the Trabzon Ortahisar Molla Siyah Mosque, which were restored within the scope of immovable cultural heritage in 2015, were determined using the Ambient Vibration Test before and after the restoration.

According to measurements implemented on the mosque before the restoration, the first three natural frequencies vary from 7.249 to 10.480Hz, and the modal damping ratios ranged from 1.378 to 2.582. After the restoration, the first three natural frequencies vary from 7.445 to 11.210Hz, and the modal damping ratios ranged from 1.172 to 2.089. All frequencies slightly increase after the restoration depending on the restoration applications. Some modes were slightly affected these restoration applications than the others. The reason of these could be the removing of non-structural and additional members. The first and third modal damping ratios were decreased while the second was increased. The first, second and third mode shapes of the mosque occur in longitudinal, transverse and torsional directions, respectively, for both before and after restoration. The changes in the modal properties highly depend on the restoration applications.

It is thought that the effect of the restoration on the static and dynamic behavior of the historical structures should be investigated before and after the restoration. The Ambient Vibration Testing is very powerful method for this purpose.

Acknowledgments

This research was implemented by using the measurement system provided by the projects from TUBITAK and Karadeniz Technical University under Research Grant No. 106M038, 2005.112.001.1and 2006.112.001.1, respectively. Many thanks to Trabzon Regional Directorate of Foundation and its valuable personnel for their supports and permissions and also the contractor of the restoration Kemal Bektaş.

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