Restoration Effects on the Experimental Dynamic Behavior of Historical Molla Siyah Mosque

Ismet Çalik[1], Alemdar Bayraktar[2], Temel Türker[2,] Ali Osman Ayan[1]

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

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 dynamic behavior of many mosques damaged on the 2011 Simav Earthquake in Turkey.

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 Molla Siyah 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 DESCPRIPTION OF MOLLA SİYAH MOSQUE

The Molla Siyah 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. Molla Siyah Mosque, Ortahisar, Trabzon, Turkey [17]

The structure of the mosque was built as a church in the XI Century initially. It was converted into a mosque before the 1557 [18]. 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 Molla Siyah 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 Molla Siyah Mosque. The artifact, which was restored by the Trabzon Directorate of Foundations in 2015, is presently open for worship and is actively being used.
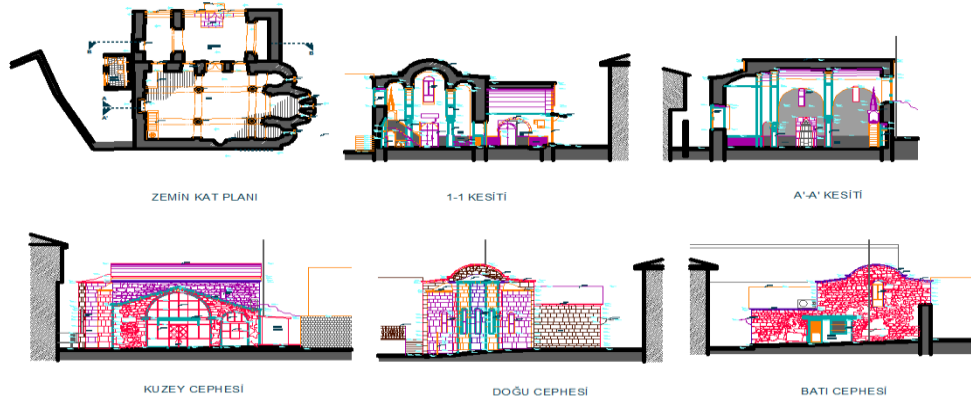

Fig. 3. Layout, inside and outside of the survey project of Molla Siyah Mosque [19]

Fig. 4. Layout, inside and outside of the restoration project of Molla Siyah Mosque [20]

3. Restoration Applications of MOLLA SİYAH MOSQUE

Within the scope of restoration works carried out by the Trabzon Regional Directorate of Foundations in 2015, 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 (Fig. 7).

Fig. 7. Joint applications

- Drainage and landscaping applications were done (Fig. 8).

Fig. 8. Drainage and landscaping applications

- The electrical fixtures were renovated and ambient lighting was completed. Also air conditioning fitted.

The images of Molla Siyah Mosque after the restoration are given in Fig. 9

Fig. 9. The images of Molla Siyah Mosque after the restoration

4. AMBIENT VIBRATION TESTS OF MOLLA SİYAH 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 [21] software and the dynamic characteristics of the structure were obtained using OMA software [22].

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 relationship between the input and output signals in the EFDD technique can be written as,

$$\left[G_{yy}(jw) \right] = \left[H(jw) \right]^{*} \left[G_{xx}(jw) \right] \left[H(jw) \right]^{T} \tag{1}$$

where [G_{xx}(jw)] is the Power Spectral Density (PSD) matrix of the input, [G_{yy}(jω)] is the PSD matrix of the output, [H*(jw)*] is the Frequency Response Function (FRF) matrix, and * and T denote complex conjugate and transpose, respectively. The derivation of the Eq. (1) can be fined in the literature so that the details will not given here [23-24].

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. Some images of the accelerometer placements and the data acquisition system are given in Fig. 10.

Fig. 10. 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. 11.
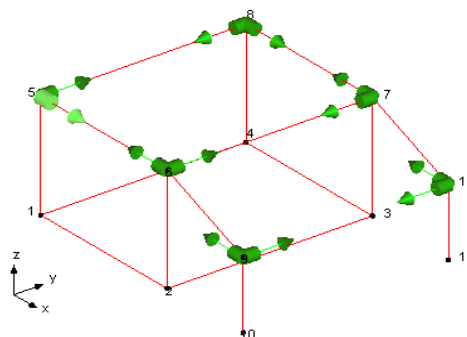
Fig. 11. A representative model of the accelerometer locations before the restoration

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 frequency response function obtained from the mosque before the restoration measurement as shown in Fig. 12.
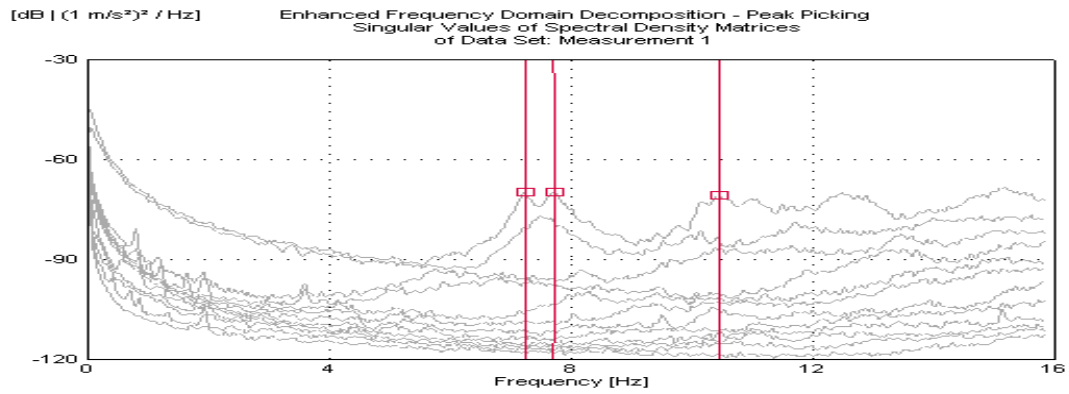
Fig. 12. The frequency response function obtained from the mosque before the restoration measurement

The first three natural frequencies and modal damping ratios before the restoration are given in Table 1. The first three mode shapes obtained from the measurements are shown in Fig. 13.

Table 1. The first three natural vibration frequencies and damping ratios of the mosque before the restoration

Number of Mode	EFDD Technique	
	Frequency (Hz)	Damping Ratio (%)
1	7.249	1.520
2	7.721	1.378
3	10.480	2.582

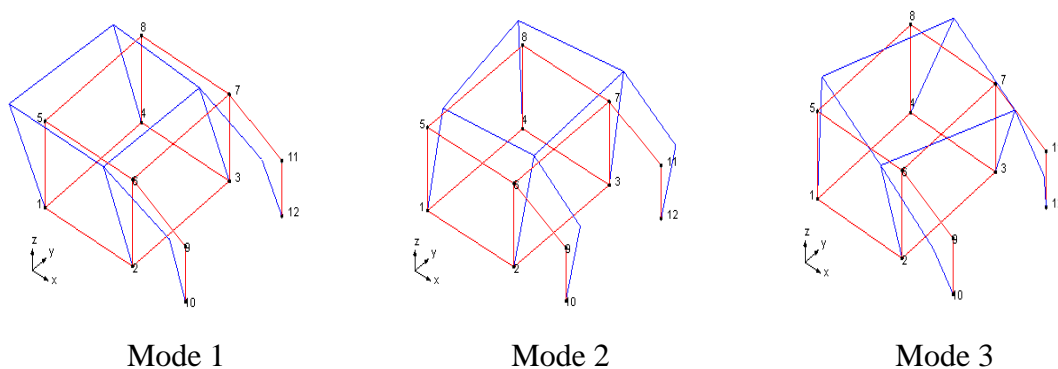Mode 1   Mode 2   Mode 3

Fig. 13. The first three mode shapes of Molla Siyah Mosque before the restoration

4.2. Measurements After the Restoration

The same representative model of the accelerometer locations given in Fig.11 are used after the restoration. There are some images of the accelerometer placements and the data collection systems in Fig. 14.

Fig. 14. 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 frequency response function obtained from the mosque after the restoration measurement is given in Fig. 15.
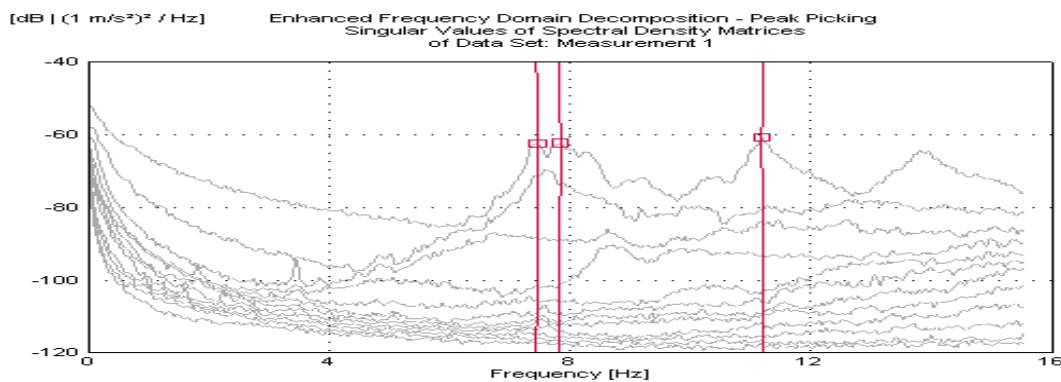

Fig. 15. The frequency response function obtained from the mosque after the restoration measurement

In Table 2, the first three natural frequencies and modal damping ratios after the restoration are given. The first three mode shapes obtained from the measurements of the mosque are shown in Fig. 16.

Table 2. The first three natural vibration frequencies and damping ratios of the mosque after the restoration

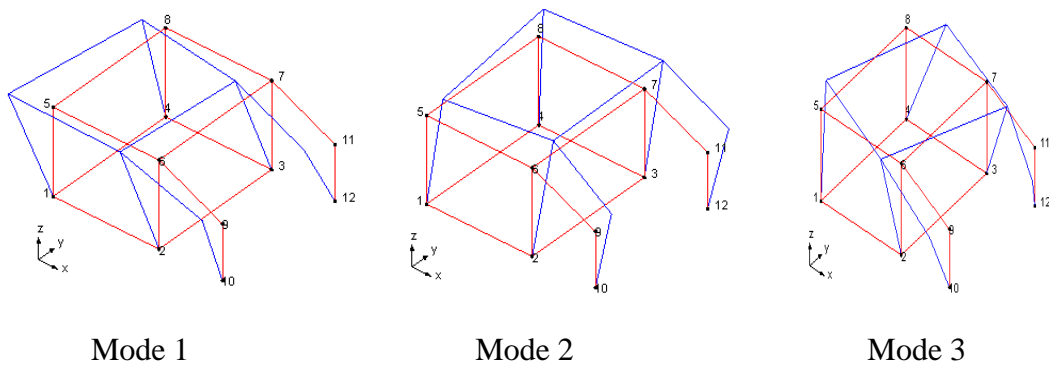| Number of Mode	EFDD Technique	
	Frequency (Hz)	Damping Ratio (%)
1	7.445	1.172
2	7.831	1.467
3	11.210	2.089

| Mode 1 | Mode 2 | Mode 3 |

Fig. 16. 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. 13 and 16 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

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.

The first, second and third mode shapes of the mosque occur in longitudinal, transverse and torsional directions, respectively, for both before and after restoration.

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

REFERENCES

[1] Turek , M., Ventura, C.E., Placencia, P., (2002). Dynamic characteristisc of a 17th centuray church in Quito, Internat Soc. Opt. Eng. 2002, IMAC-XX, Conferenece&Expositioan on Structural Dynamics, 4753, 2, 1259-1264.

[2] Durukal, E., Cimilli, S.,Erdik, M., (2003). Dynamic response of two historical monuments in İstanbul deduced from the recordings of Kocaeli and Duzce earthquakes, Bulletin of the Seismological Society of America; 93, 2, 694-712.

[3] Bayraktar, A., Türker, T., Sevim, B., Altunışık, A.C., Yıldırım, F., (2009). Modal Parameter Identification of Hagia Sophia Bell-Tower via Ambient Vibration Test, Journal of Nondestructive Evaluation, 28, 1, 37-47.

[4] Bayraktar, A., Türker, T., Altunışık, A.C., Sevim, B., (2011). Structural System Identification of Cultural Heritage Structures By Ambient Vibration Testing, WCCE-ECCE-TCCE Joint Conference 2, Seismic Protection of Cultural Heritage, Conference Proceedings, 163-173.

[5] Aras, F., Krestevska, L., Altay,G., Tashkov, L.,(2011), Experimental and numerical modal analysis of as historical masonry place, Construction and Building Materials, 25(1), 81-91.

[6] Atamturktur, S., Bornn, L., Hemez, F., (2011). Vibration characteristics of vaulted masonry monuments undergoing differential support settlement, Engineering Structures 33, 2472-2484.

[7] Lourenço, P. B., Ramos, L., F., (2011). Dynamic Identification and Monitoring of Cultural Heritage Buildings, WCCE-ECCE-TCCE Joint Conference 2, Seismic Protection of Cultural Heritage, Keynote Papers, 55-78.

[8] Atamturktur, S. and Laman, J. A., (2012), Finite element model correlation and calibration of historic masonry monuments: review. Struct. Design Tall Spec. Build., Vol:21, P: 96–113.

[9] Can, H., Ünay, A. İ., (2012). Tarihi Yapıların Deprem Davranışını belirlemek İçin Sayısal Analiz Yöntemleri, G.Ü. Müh. Mim. Fak. Dergisi, 27, 1, 211-217 (in Turkish).

[10] Tashkov, L.A., Krstevska, L., Şafak, E., Çaktı, E., Edinçliler, A., Erdik, M., (2012). Comparative Study of Large and Medium Scale Mosque Models Tested on Seismic Shaking Table, 16WCEE, Lisbon.

[11] Bayraktar, A., Çalık, İ., Türker, T., (2013). Restorasyon Sonrası Tarihi Sundura Camisi ve Minaresinin Çevresel Titreşim Testi Yöntemiyle Dinamik Özelliklerinin Belirlenmesi, Vakıf Restorasyon Yıllığı, VGM İstanbul I. Bölge Yayını, 6, 53-62 (in Turkish).

[12] Çalık, İ., Demirtaş, B., Bayraktar, A., Türker, T., (2012). Yığma Taş Minarelerin Analitik ve Deneysel Yöntemlerle Güvenliğinin Belirlenmesi; Trabzon Muhittin Camisi Minaresi Örneği, Vakıflar Dergisi, 38, 121-140 (in Turkish).

[13] Çalık, İ., Bayraktar, A., Türker, T., (2013). Tarihi Yığma Yapıların Dinamik Karakteristiklerine Restorasyon Etkisinin Çevresel Titreşim Yöntemiyle Belirlenmesi: Rize Merkez Büyük Gülbahar Camisi Örneği, 25-27.09.2013, 2. Deprem Mühendisliği ve Sismoloji Konferansı, Hatay (in Turkish).

[14] Çalık, İ., Bayraktar, A., Türker, T., (2014). Structural dynamic identification of a damaged and restored masonry vault using Ambient Vibrations, Measurument, 55(1), 462-472.

[15] Çalık, İ., Bayraktar, A., Türker, T., (2015). Yığma Taş Duvarlı Camiler İçin İlk Üç Doğal Frekans Aralığının Deneysel Olarak Belirlenmesi, Sekizinci Ulusal Deprem Mühendisliği Konferansı, TMMOB İnşaat Mühendisleri Odası İstanbul Şubesi, Bildiriler Kitabi, İstanbul, 11-14.05.2015 (in Turkish).

[16] Bayülke, N., Kuran, F., Bozkurt, O., (2015). Simav'da 2011 Depreminde Hasarlı Camilerin Onarım Ve Güçlendirme Öncesi ve Sonrası Dinamik Özellikleri, 5.Tarihi Eserlerin Güçlendirilmesi ve Geleceğe Güvenle Devredilmesi Sempozyumu, TMMOB İnşaat Mühendisleri Odası Erzurum Şubesi, Bildiriler Kitabı I, 59-70, Erzurum, 01-03.10.2015 ((in Turkish).

[17] Google Earth, (2016). Google Earth 7.1.3, www.google.com/earth.

[18] Özen, H. Tuluk, Ö.İ. Engin H.E. Düzenli H.İ. Sümerkan, M.R. Tutkun, M. Demirkaya, F.Ü. Keleş, S., (2009). Trabzon Kent İçi Kültür Varlıkları Envanteri, Trabzon: T.C. Trabzon Valiliği İl Kültür ve Turizm Müdürlüğü Yayınları, Trabzon (in Turkish).

[19] Survey Project, (2011), Directorate General of Foundations, Trabzon Regional Directorate, Envar Mimarlık Müh. Müş. Ltd. Şti, Trabzon, Turkey.

[20] Restoration Project, (2011), Directorate General of Foundations, Trabzon Regional Directorate, Envar Mimarlık Müh. Müş. Ltd. Şti, Trabzon, Turkey.

[21] PULSE, (2006). Analyzers and Solutions, Release 11.2. Bruel and Kjaer, Sound and Vibration Measurement A/S, Denmark.

[22] OMA, (2006). Operational Modal Analysis, Release 4.0, Structural Vibration Solution A/S, Denmark.

[23] Jacobsen, N. J., Andersen, P., & Brincker, R. (2006). Using Enhanced Frequency Domain Decomposition as a Robust Technique to Harmonic Excitation in Operational Modal Analysis. Proceedings of ISMA2006: International Conference on Noise & Vibration Engineering. Leuven, Belgium.

[24] Brincker, R., Zhang, L., & Anderesen, P. (2000). Modal Identification from Ambient Responses using Frequency Domain Decomposition. 18th International Modal Analysis Conference, 625-630, San Antonio, USA.