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Operational Modal Analysis of a Historical Wooden Building

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Keywords

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Abstract

Historical structures are important cultural assets that should be protected. Much attention and expertise are required to preserve these structures. One of the crucial ways of this protection is increasing the knowledge level of the structure. The aim of this study is to examine the pre-restored state of a historical wooden building placed in Çorum province in Turkey. In the study, Operational Modal Analysis (OMA) technique was used for determining the dynamic characteristics which are natural frequencies, mode shapes and damping ratios of the building experimentally. The experimental dynamic characteristics are extracted by Enhanced Frequency Domain Decomposition (EFDD) method. These initial data will be accepted as a reference for the post-restoration state of the building and the success rate of the restoration can be evaluated.

1.Introduction

One of the oldest traditional construction materials is wood. Especially it has been used in the region that has dense forested areas [1, 2]. Wood has been widely used throughout history due to its durability, easy workability, easy accessibility, renewability and aesthetic properties. Although it is a very useful building material, its numbers and ages are quite low when compared to masonry structures [2]. One of the main reasons of this situation is natural aging of materials due to different chemical, physical, and biological processes. In addition, growth of organisms that can lead to bio-deterioration such as mould, fungi and insect damage, plays a significant role in damaging the wood material [3]. In addition to long-term material damage, disasters such as fire, wind, earthquake, flood, ground settlement have destructive impact for wooden structures. Due to the material characteristics of wood, historical wooden structures should be monitor periodically and early determination should be made for necessary restoration.

Restoration efforts on the historical buildings aim to return the structure to its original form or increase structural resistance by convenient applications. Restoration of historical wooden structures can be made in some steps [4];

- replacing only decayed or damaged parts
- repair using either traditional carpentry methods or compatible modern fasteners
- strengthening using traditional or compatible materials and methods
- relieving the load on the present structure.

Historical structures are important cultural assets that should be protected. More attention and expertise are required to preserve these structures. One of the crucial ways of this protection is increasing the knowledge level of the structure. The knowledge level of the building can be increased by researching the history of the building and the interventions, determining the material properties, element connections, damaged elements and obtaining the structural behavior. Some of these operations can be done with observations, while others require machinery/equipment. With the increase in the knowledge level of the building, it can be ensured that the realistic evaluation of structural behaviors and the necessary interventions can be made correctly.

In addition to observative and experimental methods, numerical analyses can give good estimations about structural behavior and can reduce cost and time [5]. Among numerical methods, Finite Element method has been widely used in this purpose. In order to make reliable analyses the FE models should be support by experimental tests [6,7]. Operational Modal Analysis (OMA) is a very common test for structures that extract experimental dynamic characteristics of the structures. Also, OMA is used in order to calibrate the FE models.

In this paper, prior assessment of a historical wooden building located in Çorum province was made by Operational Modal Analysis, in pre-restored situation. In the study, Enhanced Frequency Domain Decomposition (EFDD) method was used to extract dynamic characteristics of the building. These initial data will be accepted as a reference for the post-restoration state of the building and the success rate of the restoration can be evaluated.

2. Description of the wooden building

The Velipaşa Han Building is located in the city center of Çorum, Turkey. Çorum province is located in the middle-north Anatolia (Fig. 1). The building is date back to Ottoman period, at the end of the 19th century.

The building was constructed with "hımış" system which is traditional system used in historical building widely in Anatolia. Timber frame system with infilled adobe (stone, brick) is the basis of the hımış

system. Also, the building walls were nailed with timber laths and were plastered with mortar. This application is called as "Bağdadi" in the Anatolian region. Some views of the building belong to before restoration are shown in Fig. 2.

Figure 1. Location of the Çorum province in the Turkey

Figure 2. Views of the building before restoration

The building was built as meeting places and for accommodation firstly. After that, in 1885, the building was enlarged and rebuilt as a hotel, which traditional name is "han". At that time the building consisted of 43 rooms at upper floor, 16 rooms at ground floor and a meeting room, 2 barns, 10 shops and a form of garden. In time, the building may have been subject to some interventions. In addition, some historical records indicate that the building was previously burned down and was re-built in 1915-1916, taking account of its unique character [8].

3. Operational modal analysis

Operational Modal Analysis, another name is ambient vibration tests are used to obtain the vibration response of structures in a non-destructive way. The vibration of structures is measured in operational and environmental conditions. Collected vibration data is processed and dynamic characteristics such as natural frequencies, mode shapes and damping ratios are obtained. Because of depending of mass and rigidity, dynamic characteristics give good estimation current situation of structures. Therefore, these parameters are widely used in structural health monitoring studies.

In order to obtain dynamic characteristics of the building, operational modal analysis was carried out. In the test, a B&K 3560 data acquisition system with 17 channels, 8340-type uni-axial accelerometers with 10V/g sensitivity, uni-axial signal cables, PULSE and OMA software were used. The frequency span was selected as 0-25Hz. The test was applied for 15 minutes. Due to the limited number of accelerometers, referenced test was applied in steps. Accelerometers were placed at the corner points of the building in the direction of both each lateral direction (Fig. 3). In order to collect signals and signal processing PULSE software [9] and OMA software [10] were used. Enhanced Frequency Domain Decomposition (EFDD) method was employed to extract dynamic characteristics. The average of the normalized singular values of spectral density matrices (ANSVSDM) of all data sets and the singular values of spectral density matrices (SVSDM) of the data set obtained by the EFDD method are given in Fig. 4.

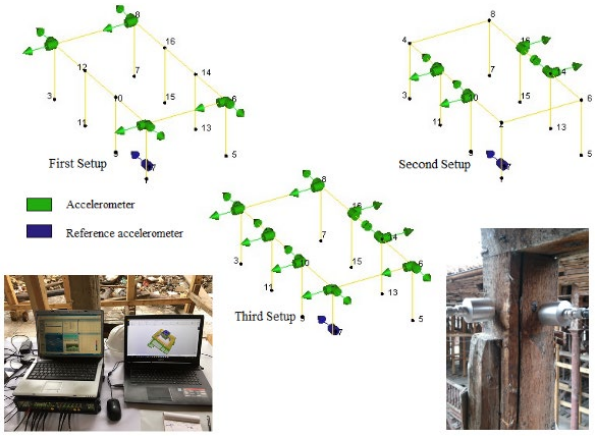
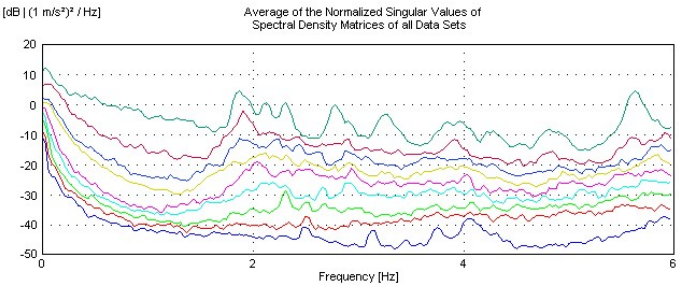
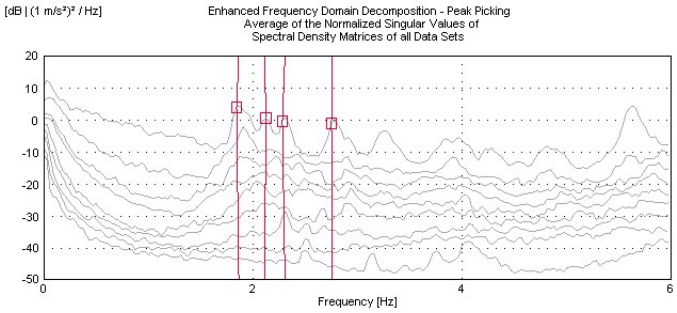


Figure 3. Accelerometer layouts in PULSE software and view of the data acquisition system and accelerometers



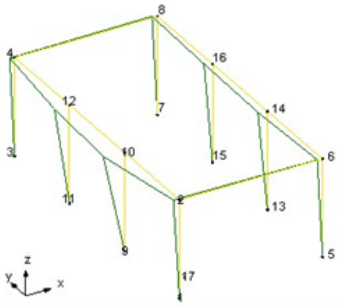
(a)



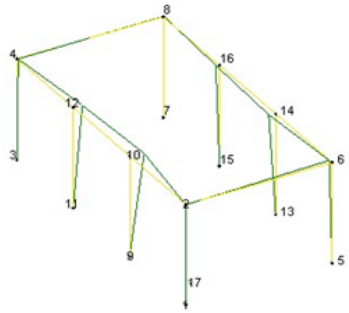
(b)

Figure 4. (a) ANSVSDM and (b) SVSDM of the data sets obtained from the EFDD method

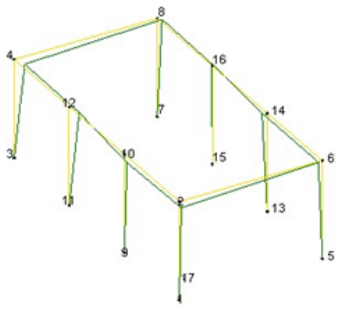
The modal characteristics (mode shapes, natural frequencies and damping ratios) of the building are given in Fig. 5. According to the results, the first four experimental modes of the building were obtained as transverse, longitudinal and torsional modes, respectively. The first four experimental natural frequencies were 1.865Hz, 2.110Hz, 2.306Hz and 2.760Hz, respectively. Also, the damping ratios of the building were obtained as 1.559%, 2.085%, 1.628% and 1.656%, respectively.



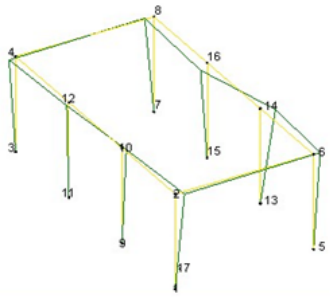
First Mode *(transverse)*
f=1.865Hz
ξ=1.559%



Second Mode *(transverse)*
f=2.110Hz
ξ=2.085%



Third Mode *(longitudinal)*
f=2.306Hz
ξ=1.628%



Fourth Mode *(torsional)*
f=2.760Hz
ξ=1.656%

Figure 5. The experimental modal characteristics of the building

4. Conclusion

This paper presents experimental testing of a historical wooden building. Operational Modal Analysis was used for measurement and EFDD technique was used for extraction of dynamic characteristics. The first four experimental frequencies of the building were obtained within 1.865-2.760Hz and the mode shapes of the building were obtained as transverse, longitudinal and torsional modes. These values are effective in achieving the monitoring of structural behavior during and after any intervention, control of restoration success rate and verification of a numerical model such as the FE model. It is important for these reasons that the modal characteristics of the building should be obtained for the current condition and after any subsequent intervention.

Due to having cultural value, historical structures are difficult to investigate with detrimental interventions. Therefore, nondestructive experimental methods are convenient for these structures.

Declaration of Conflict of Interests

The author(s) declare(s) that there is no conflict of interest. They have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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This study is a part of a comprehensive paper named "*Diagnosis and Monitoring of Historical Timber Velipaşa Han Building Prior to Restoration*" [11]. Therefore, comprehensive and detailed information about the whole study can be found in that paper.

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