Vibration Analyses on a Timber Building during Its Reconstruction

Fuat Aras*1
1Department of Civil Engineering, Istanbul Medeniyet University
Corresponding Author E-mail: fuat.aras@medeniyet.edu.tr
Corresponding Author ORCID: 0000-0002-2560-4607

Keywords
Dynamic survey, Timber pavilion, Accelerometer, Mode shapes.

Abstract
In this study, the results of vibration analyses applied to an icon timber building, Türşucuzade Pavilion, is presented. The structure is still under construction to recreate its original form. For this reason, as the first step of an ongoing project, the dynamic properties of the structure are investigated when the timber frames are completed. Operational modal analysis is pursued to extract its dynamic properties such as mode shapes and dominant frequencies of the incomplete building. Three Kinemetrics accelerometers are used with two sets of measurement. They have been located on the centroid of first floor, second floor and roof level of the building at the first set for mode shapes and dominant frequencies. Then records were gathered from three corners of second floor to obtain the torsion mode. Thereby dynamic characteristics of the incomplete timber building were extracted and evaluated.

1. Introduction
The wooden buildings of Turkey are the products of thousands of years of cultural heritage of people who live in this region. There are many distinctive styles of traditional architecture in Turkey [1]. Cultural and social factors, material availability, and climate are the main factors forming the historical and traditional environments [2]. The Turkish Ottoman-style house with its tiled roof and overhanging timber and brick bays above a heavy stone first floor wall, has become an identifiable icon recognized worldwide [3].

In high seismicity zones timber was generally used to build frame structures. Masonry was restricted to the ground floor, and lighter, more flexible wood construction was used above [4]. The configuration of the bracings reflects the layout of the structural system of contemporary steel structures. In this respect, timber buildings can be assumed as the precursor of this branch of modern engineering. Aras (2013) [5] studied the timber framed structures and details of himış and bağdadi construction techniques were presented.

Today in Turkey the number of timber structures abounds, but most are in danger of losing cultural characteristics despite recognition as cultural heritage. On the other hand, increasing public awareness has resulted in promising developments for timber buildings. Recently, the attempts of municipalities and governorships for the protection of historical structures have attracted attention. The Istanbul Metropolitan Municipality especially has spent funds and valuable care on the historical structures of the city. This study was initiated over one of the reconstruction project of an icon timber pavilion, Türşucuzade Pavilion, managed by the Istanbul Metropolitan Municipality.

Türşucuzade Pavilion is located on the heart of the historical peninsula of Istanbul. Hagia Sophia Mosque Museum, Blue Mosque, Yerebatan Cistern and Historical Hippodrome are located in its neighborhood. It was built in 19th century as a timber structure. However, in 1990, it was demolished and reconstructed with reinforced concrete structural system. Finally in 2016 the building was decided to be reconstructed with its original structural system. Detailed studies were conducted for its restitution and restoration projects [6]. After that, the reinforced concrete system was demolished and the construction of timber building was started. Figure 1 shows reinforced concrete form of the pavilion and its plan dimensions and shape with used terminology.

![Figure 1. Reinforced concrete form of Türşucuzade Pavilion and its plan](image)

This study is presented as the first step of an ongoing research which includes monitoring of dynamic properties of Türşucuzade Pavilion during its reconstruction. The reconstruction of the studied building is still continuing. The reported vibration measurements are taken from building when the timber frames are completed. In this respect, detailed information is given below. Operational modal analysis is pursued to extract its dynamic properties such as mode shapes and dominant frequencies of the incomplete building. Three Kinemetrics
accelerometers are used with two sets of measurement. They have been located on the centroid of first floor, second floor and roof level of the building at the first set for mode shapes and dominant frequencies. Then records were gathered from three corners of second floor to obtain the torsion mode. Thereby dynamic characteristics of the studied building were extracted and evaluated. During the measurement the constructional works were in progress.

2. The Studied Pavilion during the Vibration Measurements

Turşucuzade Pavilion is a three story pavilion but it contains a penthouse on the staircase. Structural system of the pavilion is completely timber and the performed reconstruction aimed to rebuild it with its original characteristics. On the other hand, the foundation of the pavilion was constructed with a combination of reinforced concrete and steel materials in order to eliminate the negative effects of soft soil propriety on the building. The acceleration measurements were gathered from the pavilion on 03.07.2017 when the construction works were continuing. Figure 2 shows the pavilion under construction on 03.07.2017.

On this date, the main structural elements, such as columns, beams and braces, were almost erected. The first and second story floor slabs were completed. The third floor slab’s main girders were placed but slab covers and roof elements were not placed yet. Figure 3 and Figure 4 shows details of structural system of the pavilion.

3. Acceleration measurements for modal identification

Three Kinematics, TSA-SMA accelerometers, with three sensors oriented along with X, Y and Z directions, were used for data collection. The linear acceleration range of each sensor is ±4 g. Each accelerometer has its own data storage unit and works separately without a mutual data acquisition system. The required synchronization for the dynamic identification is provided by GPS (Global Positioning System) antenna. The acceleration records gathered by three accelerometers at the same time are analyzed for mode extraction.

For the purpose of dynamic identification in the studied structure, two sets of measurements are taken. In the first measurement, three accelerometers are located on the area in front of stair case at each story. This location is necessitated by the uncompleted slabs of the third floor. The first set of measurement can give mode shapes of the structure through its height. In the second measurement three accelerometers are located on the three corners of the second floor. Thereby the torsional mode of the building was aimed. Figure 5 shows the used accelerometers during the second set of measurement.

The modal parameter estimation of a structural system based on its vibration response is very important and many signal processing techniques have been developed and validated. These techniques are ranging from frequency domain algorithms based on the Fourier transform, such as peak pick (PP) and frequency domain decomposition (FDD), to time domain algorithms, such as the Eigensystem realization algorithms (ERA) and the stochastic system identification (SSI) [7, 8]. The frequency domain methods are the most practical methods to apply existing civil structures [9]. In this study, PP method is preferred, since presentation of the signal in frequency domain indicates the dominant frequencies. Moreover, modal displacement in each dominant frequency is computed as the square root of the power density of the signals [10]. In that respect PP is a practical approach for modal identification.

Figure 6 shows the frequency domain presentation of the signals taken from the first set of measurement. As it is seen along with X and Y direction, two mutual dominant frequencies are detected as 2.65 Hz and 3.46 Hz between 0 and 5 Hz. This finding prove that at these frequencies the structure has modal displacements in both X and Y directions. Thereby, it can be concluded that these modes are torsional modes. The third dominant frequency of the structure in X direction is determined on 5.81 Hz, while it is on 5.12 Hz in Y direction.

The power of the signals on at the dominant frequencies can be used for mode shape extraction. Although, the first two mode shapes of the studied uncompleted timber structure were composed of torsional modes and they can be drawn to elaborate the variation of modal displacements. In that respect, the first mode shape of the structures is presented in Figure 7.
Figure 6. Frequency domain representation of the signals recorded through the height of the structure

Figure 7. Extracted mode shapes at 2.65 Hz in X and Y directions

FFT presentation of the signals, are shown in Figure 8 for the second set of measurement. As it is seen, Corner A and Corner B have the same dominant frequency and close enough power along with X direction, while the same is valid for Corner B and Corner C along with Y direction. Moreover, Corner A’s frequency representation is similar to that of Corner C in X direction. These results reveal that, X mode of the structures is formed by the movement of A-B sides of the building at 2.52 Hz. At this mode Corner C does not move. This is an indication of torsional behaviour. The same interpretation is valid for the Y mode at 2.531 Hz as the movement of B-C side but not Corner A. Finally, at 2.666 Hz all corners move along with Y direction. All these results indicate the torsional behavior of the structure. Moreover, different dominant frequencies obtained the corners can be the sign of non-rigid slab properties.

The obtained dominant frequencies are also different from that obtained in the first set of measurement. All the measurements were recorded while the constructional works were in progress. For this reason, there were many source of vibration. The previous studies revealed that the magnitude of the vibration affects the dominant frequencies of the structures [11].

4. Conclusions

Presenting the first step of an ongoing research which consists of monitoring of dynamic properties of Turuçuzade Pavilion during its reconstruction, this study determined the dynamic characteristics of the uncompleted structure. Two sets of measurement were used in dynamic identification, when the constructional works were continuing.

In the first set of measurement three accelerometers were located through the height of the structure, on three floor levels. The determined mode shapes indicated that the dynamic behavior of the uncompleted structure is composed of torsional modes.

In the second set of measurement, three accelerometers were located on three corners of the second floor. The results also showed torsional behavior of the structure. Furthermore, it is determined that, diaphragm action on the second-floor level does not exist.

The construction of the pavilion is still ongoing. There was scaffolding around the building (Figure 9). After its removal, more detailed dynamic measurements will be performed to determine the dynamic properties of the completed pavilion. The interpretation of the results altogether will give valuable knowledge about the dynamic behavior of timber structures.

Figure 8. Frequency domain representation of the signals recorded on the second floor of the structure

Figure 9. The reconstructed Turuçuzade Pavilion with the surrounding scaffolding system
Acknowledgements

This study has been performed with the equipment derived by TUBITAK project 214M235. Support of Istanbul Metropolitan Municipality and TAŞ Yapı is greatly appreciated. The author also thanks to Büşra Nur Taşkın, Mehveş Kavza Çetiner and Tank Tufan for their help during the vibration measurements.

Declaration of Conflict of Interests

The author declares that there is no conflict of interest. He has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

References


