DYNAMIC CHARACTERISTICS OF MINARETS OF
HOCA TABIP MOSQUE

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ABSTRACT

With its thousands of years of history and traces from the past, Bursa is an open-air living history museum. Unfortunately Bursa is located in the earthquake zone and many catastrophic earthquakes occurred in the past. From inscriptions, it is learned that great majority of historical buildings like mosques, madrasahs, inns were damaged by the latest earthquake occurred in 1855. Because of their slender form, minarets were influenced much more than the other structures.

Because one of the most important component of liabilities of our society is to preserve and transfer this historical heritage to our posterity, another problematic issue arise on this subject is the lack of literature about minarets. This is because that minarets were built in only Islamic regions. Furthermore, literature review shows that there are only a few scientific studies about seismic behavior of this type of structures. For the mentioned reasons, in this study, dynamic characteristics of Hoca Tabip Mosque which was built in 15th century, were evaluated. One of the in situ tests, modal analysis technique was carried out and the dynamic characteristics of the minaret were captured. At the same time the construction techniques were investigated. These results were compared with those obtained from the numerical model of minaret which was constituted using in situ size measuring. Finally, it was seen that the results from two approaches correspond to each other. In conclusion, it is shown that the numerical model which was carried out in this study represent actual structure with high accuracy.

Keywords: Historical Minaret, Modal Analysis; Dynamic Characteristics of Minaret

1. INTRODUCTION

Minaret is one of the main components of a mosque with its special architectural form. Its current use is to invite Muslims for pray. In the early years of Islam, azan was recited on the highest place of district in order to reach as many people as possible. In time high minarets were constructed near mosques and it became a tradition. The minaret has a significant role along with the mosque in an Islamic country. Minarets from different cultures have differed from each other by their architectural forms. For instance,
while Memluk style minarets generally have a huge main body, Ottoman minarets have, however, a slender body in character. Especially Ottoman Period minarets bring an added value to the silhouette of cities with their harmonious graceful forms, decoration and construction techniques. The most impressive minarets can be found in Edirne, Bursa and Istanbul all of which were capital cities in different periods of Ottoman Empire.

The seismic design procedure is more complicated compared to the static design procedure for the silos due to the destructive effects of the earthquakes. It can be observed from experienced failures of silos in recent earthquakes that failure of a silo can cause loss of stored material, environmental damage and probable injury or loss of life. Moreover, these failures indicate that the seismic behaviour of silos is still not understood sufficiently. Hence, the reliability and/or stability of these special structures against failure under seismic loads are of critical concern, and must be understood clearly. In spite of vital importance of silos, very few studies can be found in the technical literature concerning seismic response of such structures. Moreover, very few national or international standards include explicit requirements relating to the seismic design of the silos. Most silo standards do not cover the subject at all, or they refer to general building codes (Briassoulis 2009). On the other hand, Eurocode has recently introduced a simple seismic procedure for seismic actions in silos and tanks with a general suggestion (EN1998-4 2006).

Minarets, which are used by muezzin to recite the “azan” in order to invite people for pray in Islam, are placed next to or beside to mosques. Prior samples of this type of structures were impressed from lighthouses, observation towers and church towers that’s why their shapes were poly angular with huge body and were taken large spaces. Especially Ottoman style minarets differ from former types of minarets with its cylindrical, esthetic and slender form. In Islamic countries, except for reciting the azan, minarets have a significant role to indicate development, power and cultural level of cities. That’s why to indicate the importance of city, mosques with high and ostentatious minarets were constructed during this period.

Lateral loads were effected minarets much more than other type of structures because of its slender form. When it’s taken into consideration to our country is in the earthquake zone, it’s become important to investigate of behaviour of minarets under earthquake loads to preserve and transfer them to posterity. However, from the literature, it can be seen that there are only a few studies about investigation of dynamic characteristics of minarets.

Bursa is home to a great number of historical monuments such as mosques, madrasahs, etc., because of its significant role in the period of Ottoman. Bursa served as capital city and typical minarets were constructed during this period. Hoca Tabip mosques’ minaret that shows the similar characteristics of other minarets of Bursa like height, diameter, construction technique etc., was investigated and its mode shapes and natural vibration frequencies were obtained from both geometrical model of minaret by using finite element method and one of the in situ tests operational modal analysis in this study.

2. STRUCTURE AND HISTORICAL DEVELOPMENT OF MINARETS

One of the first sample of minaret was seen in Amr Mosque in Cairo. In Islamic Countries, construction of minaret became a tradition after Amr Mosque, [1]. It is come in important in religious architecture, minaret has symbolic value with mosque and contribute a considerable effect in city silhouette. Especially minarets in Tunis, Morocco, Algeria, Egypt, and Syria which called Western minarets have huge main body and were used as a dwelling except for reciting the azan. Besides that minarets which were built in Iran, Iraq and Anatolia are called eastern minarets, are used only reciting the azan so they are slimmer than western minarets.

In the 750 years of the Ottoman Empire's existence, there have been numerous historical places such as mosques, inns, Turkish baths, madrasahs, bridges etc. During the Ottoman period (1299–1922), slender cylindrical and polygonal shafts with conical caps became the exclusive form for Turkish minarets. During the early Ottoman period (1299–1437), the number or location of the minarets did not symbolize anything. Starting with the classical Ottoman period (1437–1703) the number of minarets was incorporated into the architectural composition. As a rule, only the mosques built by sultans were
allowed to have more than one minaret, usually placed at the junction of the haram (central space of the mosque) and the sahn (naves at the entrance). The minaret of other mosques was often placed in the corner at the right end of the entrance arcade, [2].

Bursa was one of the capital cities of Ottoman Empire so Ottomans built many impressive structure in Bursa. Unfortunately, it was seen that many severe earthquakes occurred in the past and a great majority of structures destroyed by earthquakes. The most important two earthquakes occurred in 1855 and from the literature we can understood that almost all minarets collapsed but few minarets which had major damages were still standing. After the earthquake, minarets were rebuilt with small height/diameter ratio to withstand lateral loads. It is a characteristic specification for Bursa’s minarets and this characteristic made very conspicuous the current historical minarets in the region of Bursa.

A classical Ottoman minaret has a standardized assembly of components or segments as shown in Fig.1. The basic elements of the minaret are: footing (temel in Turkish), boot/pulpit (kaide), transition segment (küp), cylindrical or polygonal body/shaft (gövde), stairs (merdiven), balcony (şerefe), upper part of the minaret body(petek), spire (külah), and end ornament (alem).

Figure 1. Segments of a typical Ottoman Minaret.

3. MINARET OF HOCA TABIP MOSQUE

Hoca Tabip mosque was located in the center of Bursa (Fig.2). It is called Hoca Tayyip Mosque or Aynalı Mosque because of mirror positioned at the bottom of balcony. From inscriptions, it is understood that it was built in the first half of 15. Century by Hoca Tabip Hüsnü Efendi. While the mosque was used as a madrasah at first, the structure were later converted into a mosque by adding the pulpit. The minaret was constructed by using both brick and stone known as Küfeki which was commonly used similar type of structures. The minaret, with height of nearly 14,3m, was made of both brick and Küfeki stone with a special construction technique used. The wall thickness of hexagonal
boot is 40 cm with 1.16 m inner diameter. The diameter is constant during the height but wall thickness varies from part to part. For example, while the wall thickness is 23 cm at the body, the wall thickness of upper part of the body is 15 cm. The cylindrical body and the upper part of the minaret body was constructed by using only küfek. The stairs were made of brick and was supported with small metal sheets placed under one out of the three or four steps. Although the minaret may seem adjacent to the mosque, it can be understood from the bond that it is separate from the main wall of mosque. Current circumstance of the minaret demonstrated that although the mosque and all of its components have undergone repairs recently, local deterioration is seen in bricks. Fig. 2 shows geometrical properties, photo and location of the minaret, on the map.

Figure 2. Geometrical and structural details, photo and localization of Hoca Tabip Minaret (Dimensions in cm)

4. METHOD

Operational modal analysis, which is one of the modal analysis technique, was used to obtain the dynamic characteristic of the minaret. Operational Modal Analysis (OMA) is based on measuring the output of a structure only and using the ambient and natural operating forces as unmeasured input. It is used instead of classical mobility-based modal analysis for accurate modal identification under actual operating conditions, and in cases where it is difficult or impossible to artificially excite the structure, [3]. In this method, very sensitive accelerometers were used to determine vibrations comprising from ambient effects and transfer obtained data to data analyzer. The accelerometers were placed in perpendicular direction of one another at inner and outer of the body (Fig. 3). Thus frequencies obtained for different directions which were named south-north (SN) and east-west (EW) in this study.

Software, called Signal Calc 240 produced by Data Physics Company, which optimizes data transmitted from data analyzer, was used to obtain practicable numerical values. In this study four in situ tests were performed for different frequency spans 5Hz, 10 Hz, 25 Hz and 50Hz respectively.

The numerical model for simulation of the dynamic behavior of the minaret was created with the Abaqus CAE 6.10 software. The software is a three dimensional numerical modelling program based on the finite element method. Finite element model was generated from in situ size measuring such as stair size, thickness of walls, inner and outer diameter and heights for each part etc. with modern surveying equipments and observations of construction techniques, after in situ tests. During the finite element modelling, each part of the minaret was generated independently with its real size and then these parts were unified to constitute a whole. It is too difficult to take sample for testing and specify the material properties due to the anisotropy of the masonry. This is why material properties were taken from literature and were assigned to the system. Support conditions of the minaret was also modelled as similar to real conditions as possible in order to avoid errors. After the constitution of finite element
model (Fig. 4), natural frequencies and mode shapes were obtained from the finite element analysis. By comparing the finite element and ambient vibration tests (operational modal analysis) results in order to have closer results, the finite element model was updated by changing material properties such as Modulus of elasticity and material density. In this example, the modulus of elasticity, the poisson’s ratio, and the unit weight of the stone blocks were considered as 3000 MPa, 0.3 and 25 kN/m³, respectively.

Figure 3. Accelerometer positions

Figure 4. Accelerometer positions

5. ANALYSES AND RESULTS

In this study four in situ tests were performed for different frequency spans 5 Hz, 10 Hz, 25 Hz and 50 Hz respectively and nearly same results were obtained for each span. Four accelerometers named as G1, G2, G3 and G4, were placed in perpendicular direction to one another at inner and outer places of the body. The G1 and G2 accelerometers were located perpendicular to each other at the outside of the upper part of the minaret body and the G3 was placed with same direction to the G1 but at the inner side and G4 were placed perpendicular to the G3 at the inner side (Figure 4.1). Thus frequencies were
obtained for different directions simultaneously. In this study, results were stated for two frequency spans 5 Hz and 25 Hz. Fig. 5 shows the power spectral density functions of the system, obtained from ambient vibration test method for 5 Hz and 25 Hz, respectively. 2.25 Hz, 9.08 Hz and 18.38 Hz modal frequencies were measured for x (G1-G3) direction and similarly, 2.07 Hz, 8.6 Hz, and 17.13 Hz were measured for y direction (G2-G4). It is worth mentioning here that identical modal frequencies were obtained under all conditions. Sensitivities between the 5 Hz and 25 Hz spans are different so the first two modes whose values are smaller than 5 Hz were obtained from 5Hz span with high solubility and the other four modes were obtained from 25 Hz span. The first, third and fifth frequencies belong to one direction (x) and second, fourth and sixth frequencies belong to the other (y).

![Figure 5](image)

**Figure 5.** Power spectral densities of Hoca Tabip mosques minaret in the range of 5 Hz and 25 Hz

Finite element model was constituted by using in situ size measuring after ambient vibration test. Fig.6 shows the mode shapes, frequencies and mass participation factors for perpendicular directions which were obtained from numerical model. 2.29 Hz, 9.54 Hz and 19.75 Hz modal frequencies were measured for x direction and 2.30 Hz, 9.55 Hz and 19.99 Hz modal frequencies were measured for y direction. At the same time, mode shapes were evaluated with the mass participant factor. Only the first three vibration modes, which have the ability to represent almost all system behaviour based on mass participation ratios or effective modal masses, were taken into consideration. It can be understood from the FEA results that mass participation factor at first mode is dominant and it reaches above 90% for both two directions at first three modes.

The results presented earlier in this study showed that the results obtained from both numerical model and in-situ test are almost equivalent. The results also showed that Foundation/Soil structure interaction is not effective on the response, since it is well known fact that the tall and slender structures situated on soft soil deposits are exposed to critical period lengthening effects and then such equivalence do not occur. The agreement with small difference between the results of numerical model and field tests shows that the numerical model is representative of the in-situ conditions. Table 5.1 summarizes the
results of FEA and field tests. As can be seen from Table 1, the measured and simulated values for x-direction mode differ by only about -1.78 % for the first mode and the second and third modes field behavior differed by -5.07 and -7.45 %, respectively. On the other hand, these values for y-direction are -11.11%, 11.05% and 16.70% respectively. The variations are considered to be minor for such masonry structures. Thus, the numerical model is representative of the actual structure in small strain ranges.

![Figure 6. Mod shapes of the minaret](image)

<table>
<thead>
<tr>
<th>Mode</th>
<th>Finite Element Method (Hz)</th>
<th>Mass Participation Factor %</th>
<th>Ambient Vibration Test (Hz)</th>
<th>Difference (%)</th>
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<td></td>
<td></td>
<td>X</td>
<td>Y</td>
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<tr>
<td>X mode</td>
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<td>2.25, -1.78</td>
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6. CONCLUSIONS

In this paper, we have investigated the dynamic characteristics of the minaret of the Hoca Tabip Mosque by using both FEA analyses and ambient vibration tests (operational modal analysis). On the assumption that ambient vibration test results represent the real behaviour of the minaret, numerical model was updated in FEA by changing values of material properties such as modulus of elasticity and unit weight and support conditions as in real to ensure the convergence of results for two approaches A.
total of three mode frequencies were obtained from the FEM of the systems under investigation. These modes which are extracted from among a great number of modes can be evaluated as sufficient because their participation to total mass are above 90%. Therefore, it can be easily said that only first three modes can be adequate to estimate the total response of such a system investigated in this study.

Thus, the results of the numerical investigations are expected to be useful for the better understanding and the optimization of seismic design of this particular type of historical minarets. It can also be determined that how the minaret behaves under earthquake loads which are selected from priors or artificially produced. Certainly more research is required to evaluate the dynamic characteristics of minarets in order to determine lateral load effects caused from earthquakes and provisions for earthquake damage before it occurs.

REFERENCES


