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Estimation of the dynamic behaviour of a heritage structure

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ABSTRACT

There are a lot of heritage structures in the world. In case of buildings, they have been under severe climate and some structures have been attacked by strong earthquake. Therefore, to maintain these structures is quite important to restore and to conserve for both present and future generations. Prior to the maintenance of these heritage structures, it is required to assess them. The assessment by the dynamic characteristics of these structures is one of useful methods and provides us important knowledge. To measure the dynamic structural characteristics of an old architectural structure, the vibration measurement by a tremor meter has been often applied. In this study, the dynamic assessment to Hagia Sophia, Istanbul, Turkey was performed. The tremors in the old heritage building were measured simultaneously by 8 tremor meters. By measuring the four combinations of tremor meter placements, 29 node tremors are detected.

1. INTRODUCTION

There are a lot of heritage structures in the world. A heritage structure shows the culture of nations and represents the human history itself. Especially, the world heritage structure will be the common heritage for the human beings. In case of buildings, they have been under severe climate and some structures have been attacked by strong earthquake. Therefore, to maintain these structures is quite important to restore and to conserve for both present and future generations. Prior to the maintenance of these heritage structures, it is required to assess them. The assessment by the dynamic characteristics of these structures is one of useful methods and provides us important knowledge and information of the structure. To measure the dynamic structural characteristics of an old architectural structure, the vibration measurement by a tremor meter has been often applied.

In this study, the dynamic assessment to Hagia Sophia, Istanbul, Turkey was performed (see Fig. 1). The tremors in the old heritage building were measured simultaneously by 8 tremor meters. By measuring the four combinations of tremor meter placements, 29 node tremors are detected. Each tremor meters consists of three

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orthogonally directional arranged sensors. Obtained tremors were analyzed by the frequency domain decomposition (FDD) and the natural frequencies and each vibration mode were represented. From the dynamic response of the structure, the effects of softening of a foundation and the discontinuities of the structure were estimated. Obtained results will be used for defining the material data of the structure and for presenting the restoration method. The measurements were done at the main building. Each tremor was measured 40 Hz sampling frequency and 3600 second time duration.

Fig. 1 Hagia Sophia

2. TREMOR MEASUREMENT OF MAIN BUILDING

Hagia Sophia was constructed in 537. The height of the roof top is about 56 m and the diameter of the main dome in N-S and EW directions are 31.805 m and 30.855 m, respectively (Van Nice 1965). The main dome is supported by the main arches on four mail piers. The main arches and the piers are supported by the buttress in N-S direction. The arches and the piers are also supported by the semi-domes on the secondary piers in E-W direction. The structure consists of many structural elements and provides huge spaces in the dome (Fig. 2). The structure is constructed using the bricks and stones up to the second layer and the masonries are used for building upper structures. However, the building has been attacked by the strong earthquake in several times and by the penetration of the water and moisture. Therefore, several problems are detected. In addition, due to the different depth of the bed rocks and the inelastic deformation of the materials, the building structure shows a lot of damages on the surfaces and represents the incredible structural deformation. To restore and to conserve such a heritage structure, the structural inspections are required.

The purpose of the dynamic measurement is to acquire the structural data of existing building and to access the structural performance or structural deficiencies. To obtain the structural data, the vibration records were measured. Then the natural frequencies and the vibration modes of the main building structure were determined. Fig. 3 shows the micro-tremor meter applied in this analysis. The tremor meter consists of three acceleration pickups and measures the accelerations in orthogonal direction simultaneously.

Fig. 4 shows the measuring points in this investigation. The main structure shown in Fig. 2 is transformed into skeleton as shown in Fig. 4. Node numbers are denoted at each node. Node numbers 4 8 12 and 15 on the dome cornice are coincide with the number in Fig. 4. 8 micro-tremor meters are placed on the node. Each tremor was measured 40 Hz sampling frequency and 3600 second time duration. One micro-tremor meter is placed on one fixed point and the other 7 micro-tremor meters are moved on point by point. Firstly, the tremors at the base floor, the gallery level, the second cornice and the dome cornice on the northern side of main building were measured. Secondary, tremors on the southern side of main building were measured as the same manor.

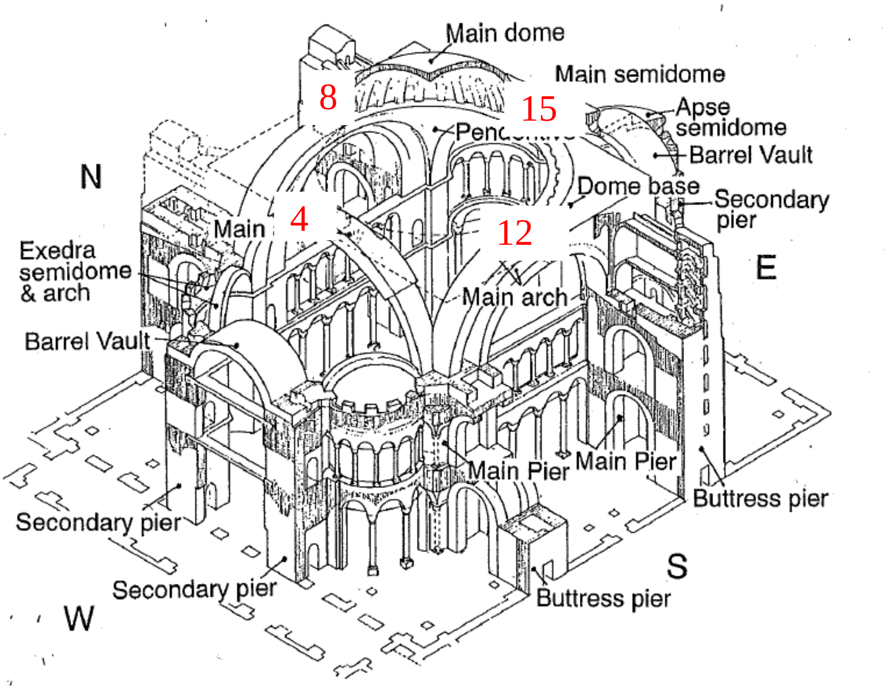

Fig. 2 Components of the building (Mainstone 1998)

Fig. 3 Micro-tremor meter

Finally, the piers at the entrance gate and the piers under apse dome were measured. The tremors are totally measured at 29 nodes. All the tremor data obtained in this measurement were collected and were analyzed by FDD (Frequency Domain Decomposition) and the natural frequency and vibration characteristics were obtained.

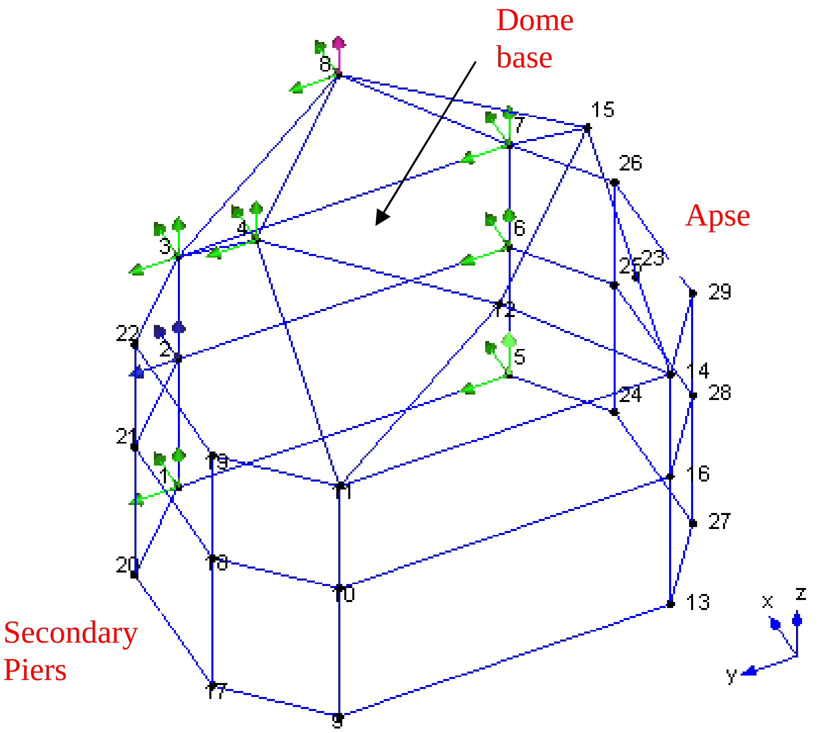

Fig. 4 Measuring Model

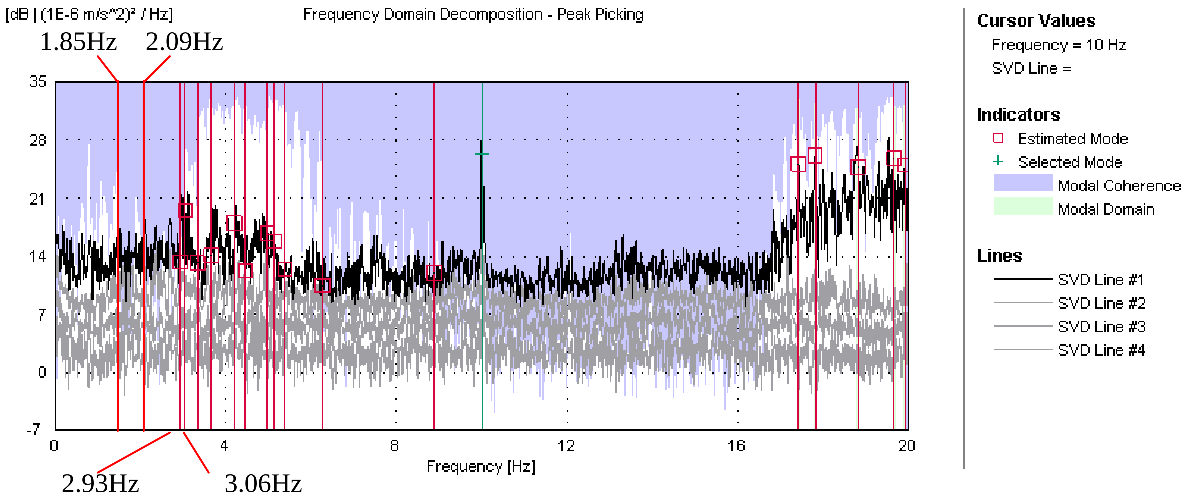

Fig. 5 Frequency domain responses

3. DYNAMIC CHARACTERISTICS OF MAIN BUILDING

Using the FDD analysis, the frequency domain expressions of four measuring record sets were combined and represented (see Fig. 5).

From Fig. 5, several spectral peaks were obtained. For example, the frequencies 1.85 Hz and 2.09 Hz are the same results obtained by Çakmak (1995). 1.85 Hz and 2.09 Hz are natural frequency for the predominant vibration and for the vibration in N-S direction, respectively.

However, in this analysis, the first and the second peak frequencies were 2.93 Hz and 3.06 Hz, respectively. The vibration modes of 2.93 Hz and 3.06 Hz are shown in Figs. 5 and 6, respectively. In case 2.96 Hz, the south east second cornice (node 14) shows the vibration with large amplitude. Also, the building at south east pier moves, even it is a column base. From the analysis of Çukmak, the southern portion of the building has deeper foundation than the nortan portion.

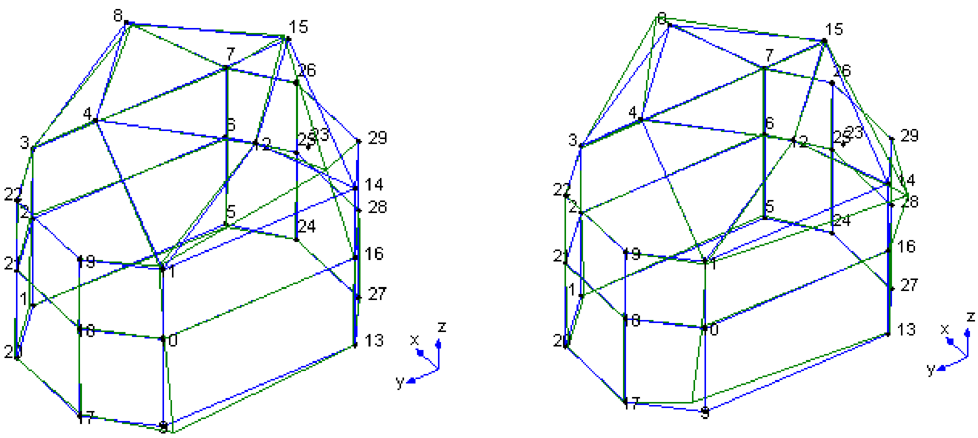

Fig. 5 Vibration mode shape (2.93 Hz)

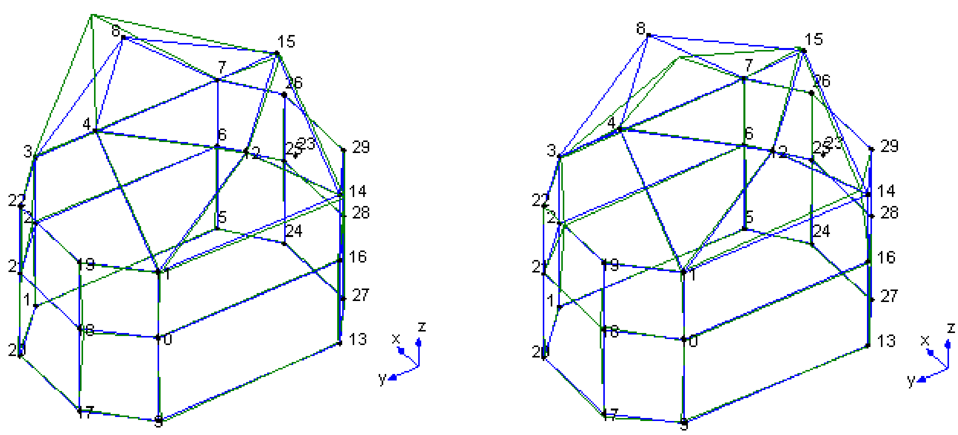

Fig. 6 Vibration mode shape (3.06 Hz)

On the other hand, in 3.06 Hz, the north tympanum vibrates from north to south and upward to downwards largely. It has the possibility of the effects of cracks around the north tympanum. The higher frequencies over 16 Hz depend on each structural elements such floors and columns.

4. CONCLUSIONS

In this study, the measurement of tremors of Hagia Sophia, Istanbul, Turkey was performed to investigate the vibration characteristics of the Hagia Sophia main building. The tremors in the old heritage building, Hagia Sophia, were measured simultaneously by 8 tremor meters. This work will bridge to the following research to assess the structural safety of Hagia Sophia.

From the measurement of the Hagia Sophia, following conclusions are obtained and the required future works are represented.

1. FDD analyses of recorded data show the vibration characteristics of maim building including the possibilities of propagated cracking of the structure and the foundation conditions. Therefore, to analyze the recorded data combined with earthquake motion recorded in and around the building, the precise characteristics and defecting of the building will be represented precisely using FE Analysis (Yamasaki 2012).
2. Hagia Sophia is the complicate structure. Therefore, to analyze and to identify the natural frequency and vibration mode with the numerical analysis using FEM combining with 3D scanning data will be required (Takanezawa 2013).
3. Hagia Sophia is quite large structure. Therefore, the measurements of other small size of dome structures will be important to identify the recorded data and the numerical results prior to investigate such huge building. These bring us the useful data to analyze the Hagia Sophia and to represent the effective restoration scheme of the Hagia Sophia.

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