Turkish Journal of Science & Technology
Volume 13(1), 93-98, 2018

Determining Dynamic Characteristics Of Reinforced Concrete Minarets And Updating Of Their Finite Element Models Using Environmental Vibration Data

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(Received: 05.02.2017; Accepted: 01.04.2017)

Abstract

Structures are exposed to various dynamic effects such as earthquake, wind and traffic load. It need to be taken various measures for surviving the structures under dynamic loads. Taking the appropriate measures depends on the well-known of dynamic behavior of existing structures. This behavior of the structure can be known through analytical or experimental methods. In the analytical methods, many acceptance is made in finite element modeling of the structure and it is considered that the created model represents its existing case. However, it is rather difficult to fully represent of the existing structure with the accepted assumptions. In experimental methods, the dynamic characteristics of the structure (natural frequencies, mode shapes and damping ratios) are determined for the present case. Using these dynamic characteristics, the existing analytical model of the structure can be updated and the evaluation of the structure according to this new model can be made more realistic. In this study, analytical and experimental analyses of the minaret of Firat University Engineering Campus Mosque were carried out. The finite element model has been updated depending on the dynamic characteristics obtained from the experimental analysis.

Keywords: Dynamic characteristics; Reinforced concrete minaret; Analytical model; Environmental vibration data; updating of finite element model.

Betonarme Minarelerin Dinamik Karakteristiklerinin Çevresel Titreşimler Kullanılarak Belirlenmesi Ve Sonlu Eleman Modellerinin Güncelleştirilmesi

Özet

Yapılar deprem, rüzgâr, trafik yükü gibi çeşitli dinamik etkilere maruz kalmaktadır. Yapıların dinamik yükler altında ayakta kalabilmeleri için çeşitli tedbirlerin alınması gerekmektedir. Uygun tedbirlerin alınması mevcut yapıların dinamik davranışlarının iyi bilinmesine bağlıdır. Yapının bu davranışının bilinmesi, analitik ya da deneysel yöntemler yardımıyla mümkün olabilmektedir. Analitik yöntemlerde, sonlu elemanlar modeli oluşturulurken birçok kabul yapılmakta ve oluşturulan modelin mevcut yapıyı temsil ettiği düşünülmektedir. Oysaki yapılan kabullerle mevcut yapının tam olarak temsil edilmesi oldukça zordur. Deneysel yöntemlerde ise, yapının dinamik karakteristikleri (doğal frekansları, mod şekilleri ve sönüm oranları) mevcut durum için belirlenmektedir. Bu dinamik karakteristikler yardımıyla yapının mevcut analitik modeli güncelleştirilebilir ve bu yeni modele göre yapının değerlendirilmesi daha gerçekçi olarak yapılabilir. Bu çalışmada, Elazığ ili Fırat Üniversitesi Mühendislik Kampüsü Camisinin minaresinin analitik ve deneysel analizleri gerçekleştirilmiştir. Deneysel analizden elde edilen dinamik karakteristiklere bağlı olarak yapının sonlu elemanlar modeli güncelleştirilmiştir.

Anahtar Kelimeler: Dinamik karakteristikler; Betonarme minare; Analitik model; Çevresel titreşim verileri; Sonlu elamanlar modelinin güncelleştirilmesi.

1. Introduction

As depending on the fast progress of the technology, the produced electronic devices enable easy observation of the behaviors of living things and also enable observation of the behaviors of the structures [1]. The analysis of the acceleration signals obtained with the help of accelerometers gives some information about the structure. By comparing the results obtained for different situations, it can be determined whether there is any change in the behavior of the structure. Experimental Modal Analysis method is widely used for this purpose [2]. The basis of experimental modal analysis studies, which have application scope in many engineering disciplines, is based on the 1940s. At early times, non-practical approaches was mostly used since transformers measuring dynamic forces were simple. In the 1960s, the modern era of experimental modal analysis began as depending on the development of digital computers and Fast Fourier Transforms [3].

Structures are exposed to various dynamic effects such as earthquake, wind and traffic load. It need to be taken various measures for surviving the structures under dynamic loads. Taking the appropriate measures depends on the well-known of dynamic behavior of existing structures. While the dynamic characteristics of the structures (natural frequencies, mode shapes and damping ratios) are used to determine its dynamic behavior with using the mode superposition method, it also helps to control the accuracy of the analytical model. These characteristics cannot be at the expected values due to cracking, fatigue, collapse of support in the structures and/or workmanship faults during construction [4]. Therefore, it is considered that using of the dynamic characteristics obtained from analytical methods in determining dynamic response of the structures can be given incorrect results. Since experimental methods are applied on the current state of the structures, dynamic characteristics obtained by these methods reflect the current situation. Updating of analytical models of structures with respect to results of experimental methods will lead to more realistic results [5-7].

There are many studies on determining the dynamic characteristics of structures based on experimental measurements [8-14]. In these studies, the dynamic characteristics of many structures such as minaret, tower, mosque, church, etc., which are constructed as reinforced concrete/masonry, are determined.

2. Experimantal Method

Vibration is the behavior of structures under initial conditions or under applied external loads. Basically, there are two types of vibration, free and forced vibration [7,15]. Free vibration occurs under the initial conditions of the structure and ends with the effect of damping after a while. In this type of vibration, the fundamental frequency is the smallest frequency and usually the most effective frequency of the structure. If an external load is applied to the structure, the name of this vibration is the forced vibration. As long as the structure is exposed to external load, vibration of the structure continues [16]. The experimental method to be used varies depending on whether vibration is known or not. If the numerical values of vibration applied to the structure are known, Conventional Modal Analysis method, if the numerical values of the vibration are unknown and the structure vibrates under of environmental effects, Operational Modal Analysis (OMA) method is used. OMA method are not needed expensive devices when compared to the conventional modal analysis method at large volume structures for artificial excitation [5,17].

OROS-OR36 Multichannel Noise and Vibration Analyzer is used in experimental measurements based on the OMA method (Figure 1).

Figure 1. OROS-OR36 Multichannel Noise and Vibration Analyzer.

3. Numerical Application

In this study, theoretical and experimental analyses of the minaret of Firat University Engineering Campus Mosque (Figure 2) were carried out. This minaret had built as reinforced concrete.

3.1. Theoretical analysis

The analytical model of the selected reinforced concrete minaret was created with shell elements by using SAP2000 finite element package program. In the initial analytical model, the modulus of elasticity of the concrete was taken as $11*10^3$ MPa (Figure 3). The values of first three frequencies obtained from the modal analysis using the initial analytical model are 2.30, 2.45 and 8.77, respectively.

Figure 2. Minaret of Firat University Engineering Campus Mosque.

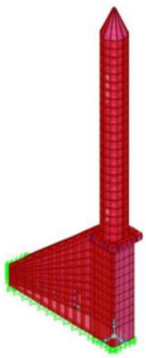


Figure 3. Finite element model of Minaret.

3.2. Experimental analysis

Creating Experimental Model: OMA method were used in the experimental measurements of the structure. Measurements were taken with the accelerometers attached to 4 different points of the structure. The measurement points on each floor are selected as points having the same coordinates in the "x" and "y" directions. 8 accelerometers were totally used for the measurement without reference as two accelerometers each of which are placed in x and y directions for each point (Figure 4).

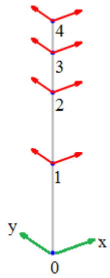


Figure 4. The accelerometer system for without reference measurement.

Experimental Measurement and Updating Analytical Model: After the preliminary tests of structure carried out, (finite element model solutions and in-situ wide frequency range measurements), the measurement frequency range, time and other parameters were determined. The Modal Indication Function was created by processing raw signals obtained from measurements. With the help of this function, first three frequencies were selected and values of that are 2.15, 2.32 and 9.56 Hz, respectively. Mode shapes with related these frequencies were given in Figure 5-6.

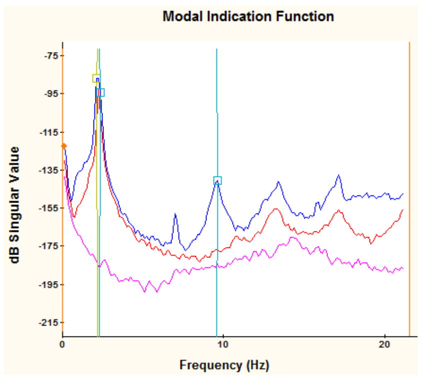


Figure 5. Selected frequencies from modal indication function.

The compatibility of analytical and experimental modes was controlled by a criterion called Modal Assurance Criteria (MAC). This criterion [16] is defined by the (1) equation.

$$\mathrm{MAC}\left(\psi_a, \psi_d\right)=\frac{\left|\psi_a{}^T \psi_d\right|^2}{\left(\psi_a{}^T \psi_a\right)\left(\psi_d{}^T \psi_d\right)} \quad (1)$$

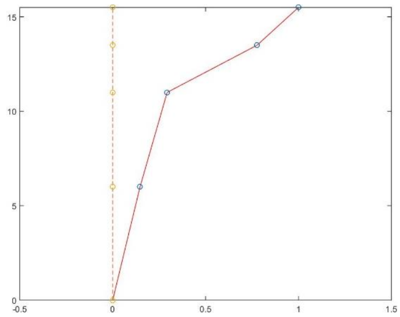
where ψ_a and ψ_d refer to analytical and experimental mode shape, respectively. If the analytical and experimental mode shapes are entirely the same, the MAC value must be 1, otherwise this value must be less than 1.

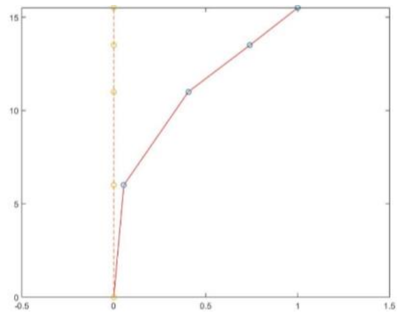
In comparison of the initial analytical model solutions and experimental results (Table I), the frequency and MAC values were seen to be compatible for both method. It was also given experimental damping ratios in Table I. It is thought that differences between analytical and experimental frequencies can be minimized if the initial model of the structure is updated. The minaret mass is considerably known. There is more uncertainty in stiffness. Factors affecting the stiffness can be expressed as concrete elasticity and boundary conditions. Here, elasticity module of concrete was updated as $10*10^3$ MPa.

Table 1. Comparison of Initial Analytical Model Solutions and Experimental Results.

Mode Number	Analytical Frequencies (Hz)	Experimental Frequencies (Hz)	Experimental Damping Ratios (%)	MAC (%)
1	2.30	2.15	4.09	96.281
2	2.45	2.32	3.29	91.841
3	8.77	9.56	2.89	90.419

Modal analysis of the updated analytical model was performed and, the first three frequencies and mode shapes were presented in Table II and Figure 7, respectively. Now, the frequency and MAC values of first two modes for the updated analytical model are closer to the results of the experimental method.


1. Mode


2. Mode

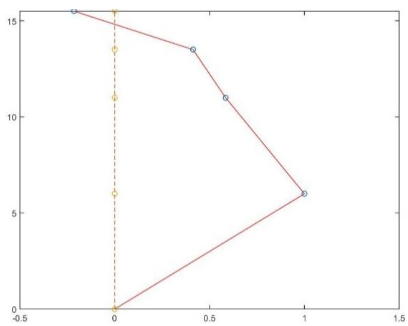
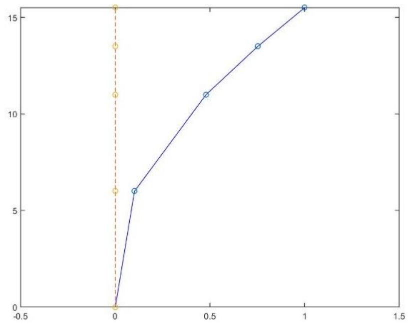
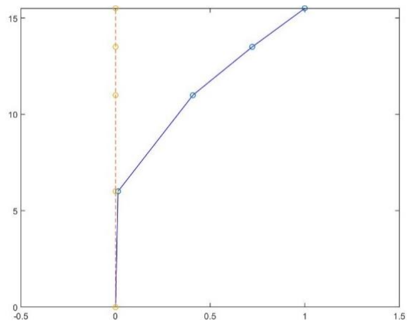

3. Mode

Figure 6. Mode shapes for selected frequencies.


1. Mode


2. Mode

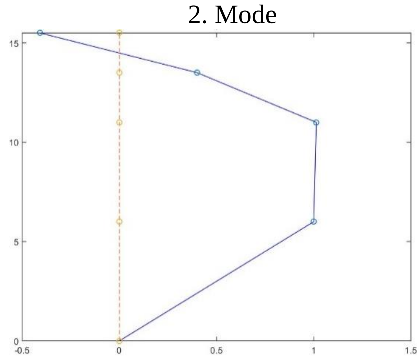

3. Mode

Figure 7. The first three modes obtained using updated analytical model

Table 2. Comparison of Updated Analytical Model Solutions and Experimental Results.

Mode Number	Updated Analytical Frequencies (Hz)	Experimental Frequencies (Hz)	MAC (%)
1	2.24	2.15	96.366
2	2.34	2.32	95.898
3	8.58	9.56	90.397

4. Conclusions

In this study, dynamic characteristics of a reinforced concrete minaret were determined by using Operational Modal Analysis (OMA) method and the analytical model of this minaret was updated. The analytical model solution was obtained by using SAP2000 finite element package program. Modal analysis of the analytical model was performed to find the dynamic characteristics and the first three frequencies were obtained at the range of 2.30-8.77 Hz.

The OROS-OR36 Multichannel Noise and Vibration Analyzer was used for experimental measurements. In these measurements, the first three frequencies are in the range of 2.15-9.56 Hz and the damping ratios related to these frequencies are in the range of 2.89-4.09%.

In comparison of the initial analytical model solutions and experimental results, the frequency and MAC values were seen to be compatible for both method. Differences between analytical and experimental frequencies can be minimized if the initial model of the structure is updated. The minaret mass is considerably known. There is more uncertainty in stiffness. Factors affecting the stiffness can be expressed as concrete elasticity and boundary conditions. Here, elasticity module of concrete was updated. The first three frequencies of the modal solutions of the updated model were obtained in the range of 2.24-8.58Hz. For the frequency and MAC values of first two modes, modal solution of the updated analytical model are closer to the results of the experimental method.

It has also been shown in this study that the dynamic characteristics of structures can be obtained using experimental methods and the analytical models can be updated according to the results of the experimental methods.

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