Ambient Vibration Based Model Updating Effects on the Earthquake Response of Tall Buildings

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ABSTRACT

The study investigates ambient vibration based model updating effects on the seismic behaviour of a RC tall building subjected to far and near-fault ground motions. A 17-storey building built in Giresun, Turkey is selected as an application. Firstly, 3D initial finite element model of the selected building is created and determined analytical dynamic characteristics. Then, experimental dynamic characteristics of the building (frequencies, mode shapes, damping ratios) are determined by Operational Modal Analysis Method from the ambient vibration tests. According to experimental results, initial finite element model is calibrated by using boundary conditions and material properties. Initial and calibrated finite element models of the building are analysed under far and near-fault ground motions. The displacements, velocity and accelerations from the analyses are compared with each other.

Keywords: Model Updating, Tall Buildings, Near-Fault Ground Motion, Ambient Vibration Testing, Seismic Response

1. INTRODUCTION

Nowadays, in developed and in developing countries, a considerable increase is observed in the construction of tall buildings. Safety evaluation of existing tall buildings to earthquake motions is very important. Dynamic characteristics such as natural frequencies, damping ratios and mode shapes are one of the most important parameters for the safety evaluation of tall buildings. The dynamic characteristics of engineering structures can be obtained by finite element method and experimental measurement methods. The most commonly used experimental measurement method is Operational Modal Analysis (OMA). In recent years, there has been an increasing interest in determination of dynamic characteristics of tall buildings by OMA. Ventura and Schuster [1], Wu and Li [2], Miyashita et al. [3], Xu and Zhan [4], Li et al. [5-8], Brownjohn et al. [9] implemented full-scale measurements of tall buildings. Li and Wu [10] created seven 3D FE models of a 78-story super-tall building, and numerical results were compared with their field measurements to identify the modelling errors for the purpose of updating FE models. Pan et al. [11] presented numerical studies on dynamic responses of the tallest building in Singapore with correlation with their field measurements. Chassiakos et al. [12] performed a study on ambient vibration data collected before, during, and after the structural retrofitting.

Near-fault ground motions which expose the structure to high input energy in the beginning of the earthquake have the potential to cause a large response and considerable damage to structures [13]. Therefore, structural response to near-fault ground motions has received much attention in recent years. The effects of near-fault ground motions on civil engineering structures such as buildings and bridges, etc., have been investigated in many recent studies [14-19].

This paper aims to investigate the effect of ambient vibration based model updating effects on a tall RC building under far and near-fault ground motions. Firstly, the analytical dynamic characteristics are obtained by using the initial finite element model. Then experimental dynamic characteristics are extracted using Enhanced Frequency Domain Decomposition technique. Finite element model of the building is updated by changing of material properties and boundary conditions to eliminate the differences between analytical and experimental dynamic characteristics. Linear seismic behaviours of the building for both initial and updated finite element models are determined under the selected earthquake ground motions.

2. FORMULATION

The experimental dynamic characteristics of the structure were determined by Enhanced Frequency Domain Decomposition (EFDD) technique. In this technique, the natural frequencies, modal damping ratios and mode shapes were extracted from the power spectra by selecting peak values. The relationship between the unknown input and the measured responses can be written as [20-21],

$$G_{yy}(jw) = H(jw)^{*}G_{xx}(jw)H(jw)^{T} \tag{1}$$

where G_{xx} is the Power Spectral Density (PSD) matrix of the input signal, G_{yy} is the PSD matrix of the output signal, H is the Frequency Response Function (FRF) matrix, and * and T denote complex conjugate and transpose, respectively.

3. APPLICATIONS

3.1. Description of Selected Building

The seventeen-storey building that is constructed in Giresun, Turkey is one of the highest buildings in the city. It has a rectangular plan, two basements, a ground floor, fourteen normal floors, and an attic. The height of the building is 47.6m and its dimensions are 20 m x 30 m. The floor height of the building is 2.8m. The building has a raft foundation. While performing measurement, all floors except the basements were built with brick walls. The view, plan and section of the building are given in Fig. 1.

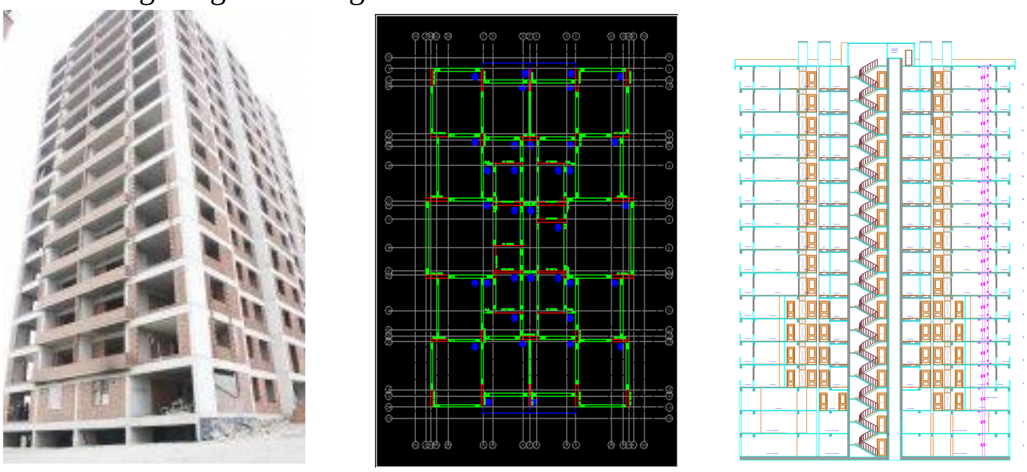


Fig. 1. The view, plan and section of the selected building

3.2. Theoretical Modal Analysis of the Building

Three-dimensional finite element model of the building was created by SAP2000 [22] program. The building was modelled by using plane and frame elements. The beams were modelled by the frame elements, and the shear walls and floors were modelled by the plane elements. 35053 joints, 4522 frames, and 41068 plane elements were used to model the building. All degrees of freedom under base of the building are assumed as fixed. The initial finite element model is given in Fig. 2.

Two different material properties were considered such as concrete and brick. The material properties assumed in the analyses are given in Table 1. The first three natural frequencies and mode shapes obtained from analytical modal analysis of the building are given Fig. 3, respectively.

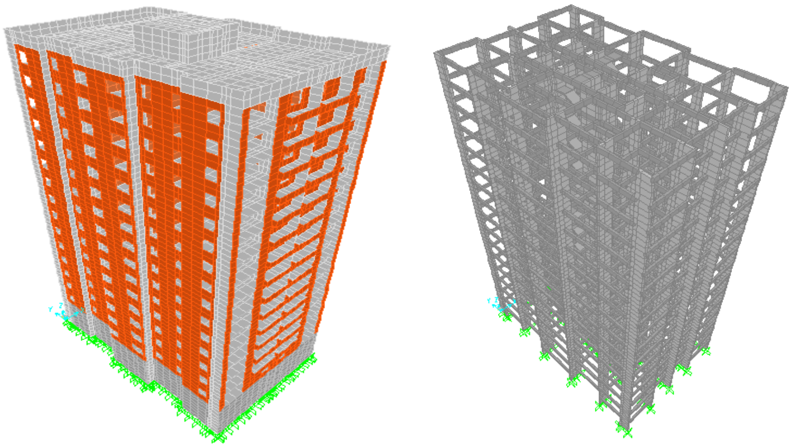
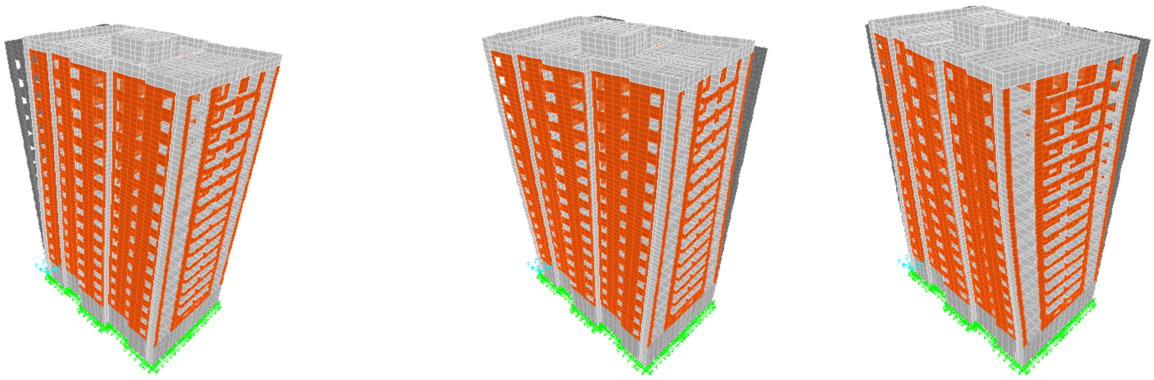


Fig. 2. The initial finite element model of the building

Table 1. Material properties used in theoretical modal analysis of the building

Materials	Modulus of Elasticity (N/m^2)	Poisson Ratio	Density (kg/m^3)
Concrete	3.2E10	0.2	2450
Brick	3.2E9	0.2	1600



1st Mode (f_1=1.639Hz) 2nd Mode (f_2=1.819Hz) 3rd Mode (f_3=1.907Hz)

Fig 3. The first three analytical mode shapes of the building

3.3. Operational Modal Analyses of the Building

The full-scale vibration test of the building was conducted by Operational Modal Analysis (OMA) method under ambient vibrations. During the ambient measurements of the building, B&K 8340 type uni-axial accelerometers which have 10V/g sensitivity, B&K 3560 type data acquisition system with 17 channels, PULSE [23] and OMA [24] softwares were used.

The experimental dynamic behavior of the building was determined by taking the measurements from different floor levels. Total four different measurements with a reference sensor were implemented. The measurements were taken from the ground floor level, the sixth floor, the eleventh floor and the fifteenth floor, which is attic. All measurements were taken for 30 minutes. The total measurement setup and location of the accelerometers are given in Fig. 4. The power spectral density matrices of the building obtained using the EFDD technique are depicted in Fig. 5. The first three experimental natural frequencies and mode shapes of the building are given in Fig. 6.

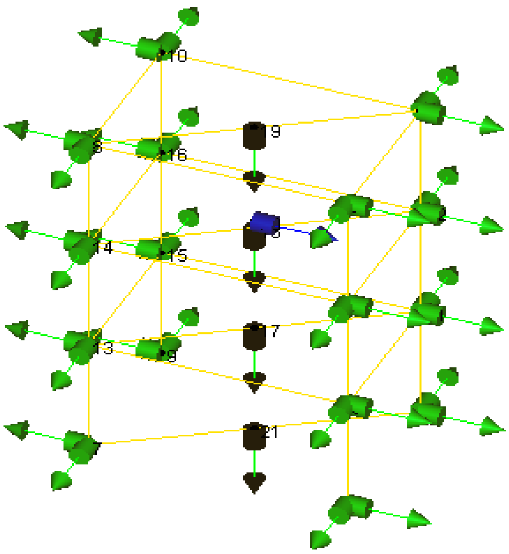


Fig. 4. Total measurement setup and location of the accelerometers

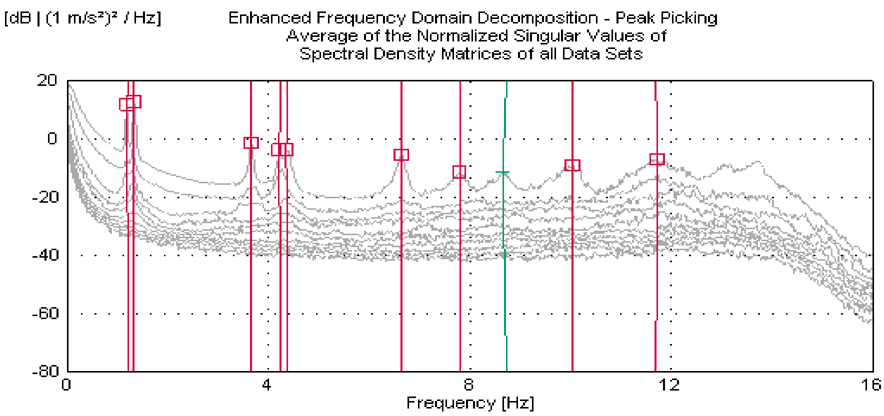
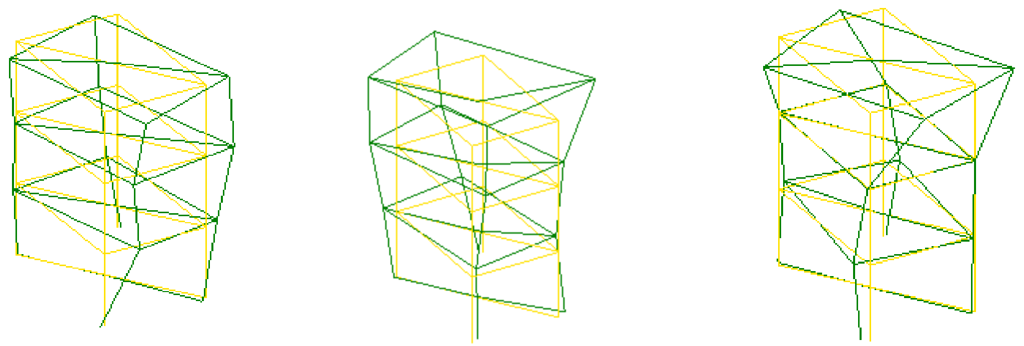


Fig.5. The power spectral density function from the EFDD technique



1st Mode (f_1=1.184Hz) 2nd Mode (f_2=1.328Hz) 3rd Mode (f_3=3.665Hz)

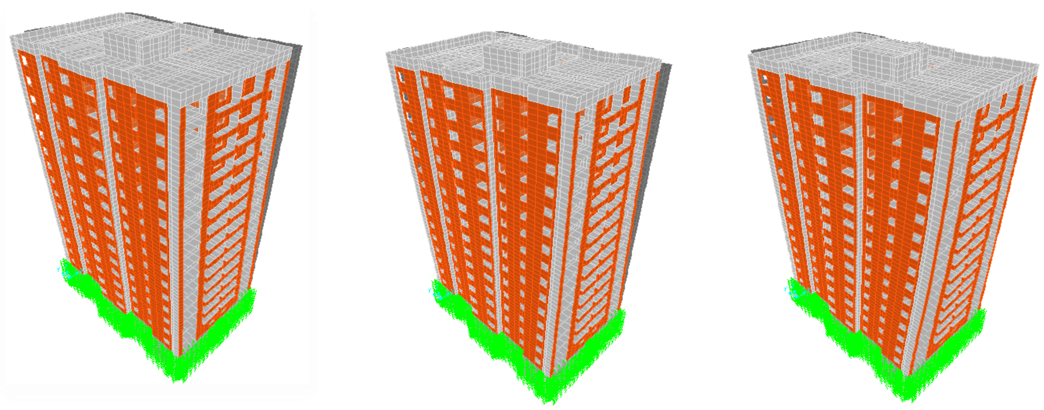
Fig. 6. The first three experimental mode shapes of the building

3.4. Finite Element Model Updating of the Building

When the natural frequencies and mode shapes obtained from the analytical and experimental studies are compared, it is seen that there are some differences between the results. Therefore, it needs to calibrate the initial analytical model in order to determine the real behavior of the building. For the calibration, modulus of elasticity of brick and boundary conditions are considered. The experimental, initial and updated natural frequencies are given in Table 2. The calibrated mode shapes are presented in Fig. 7.

Table 2. The experimental and analytical natural frequencies of the building

Mode Numbers	Natural Frequencies (Hz)			
	Experimental	Initial Model	Updated Model	Differences (%)
1	1.184	1.639	1.184	0.00
2	1.296	1.820	1.291	0.39
3	1.328	1.907	1.370	3.16



1st Mode (f_1=1.184Hz) 2nd Mode (f_2=1.291Hz) 3rd Mode (f_3=1.370Hz)

Fig. 7. The first three mode shapes of the updated building model

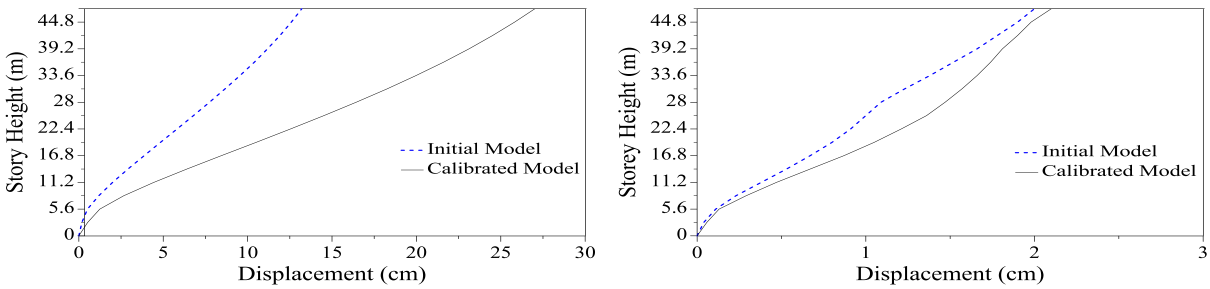
3.5. Analyses of the Building for Earthquake Motions

Duzce earthquake in 1999 as a near fault ground motion and Imperial Valley earthquake in 1979 as far fault ground motion are selected for the analysis. Some characteristics of these earthquakes are given in Table 3 (M: magnitude, d: distance, PGA: peak ground acceleration, PGV: peak ground velocity, PGD: peak ground displacement).

Table 3. Characteristics of the selected near and far-fault ground motions [25]

Earthquake	Record/Component	M	d (km)	PGA (cm/s^2)	PGV (cm/s)	PGD (cm)
1999 Duzce	DUZCE/DZC270	7.1	8.2	524.84	83.5	51.59
1979 Imperial Valley	IMPVALL/H-VCT345	6.5	54.1	163.83	8.3	1.05

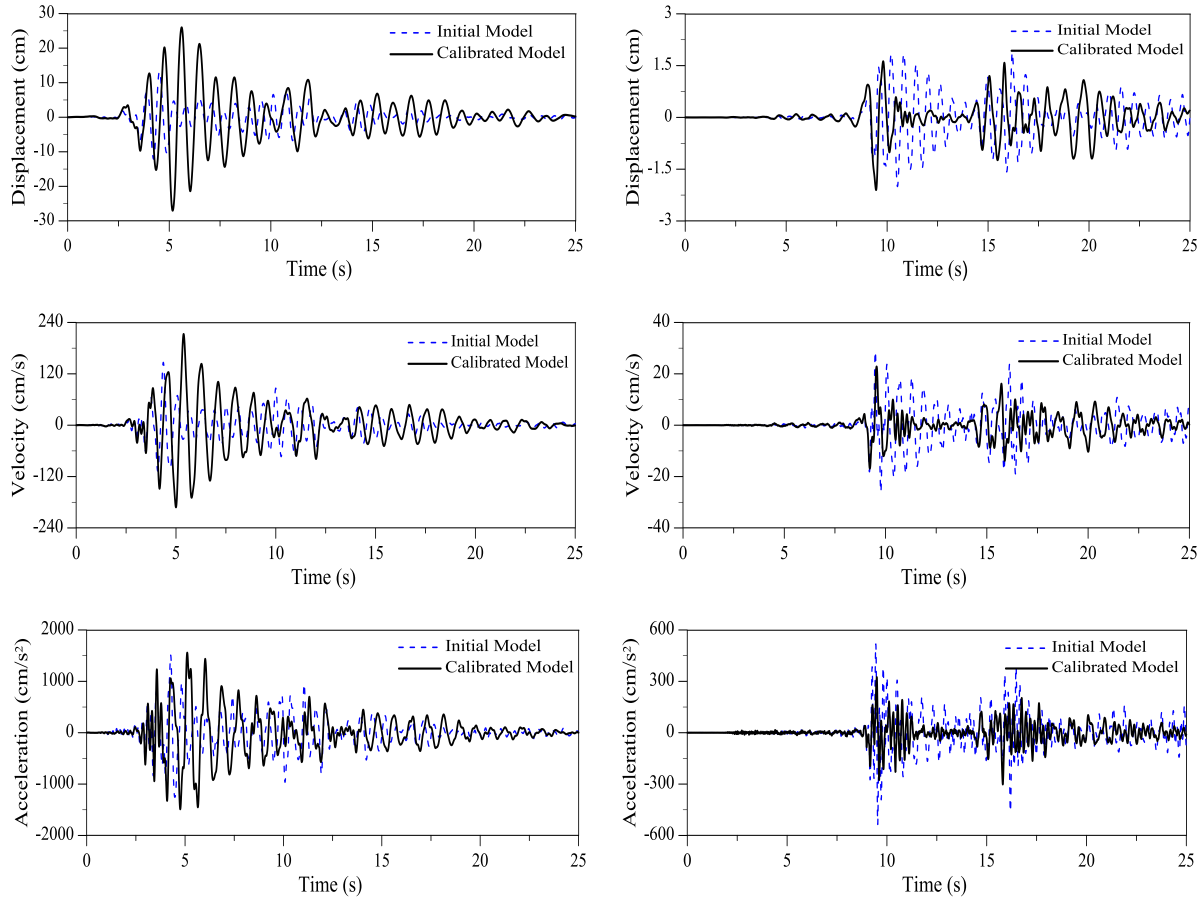
The initial analytical and updated models of the building are analyzed under earthquake motions linearly. The ground motions are applied to the building in X-axis direction (in the weak direction of the building). The relationship between height and displacements under earthquake motions is given in Fig. 8. As can be seen from Fig. 8, the displacements increase with increasing story height. In addition, it is seen that the displacements obtained from the calibrated model are bigger than those of the initial model for both far and near-fault ground motions.



a) 1999 Duzce Earthquake b) 1979 Imperial Valley Earthquake

Fig 8. The relationship between story height and displacements under earthquake motions

Displacements, velocities and accelerations occurring on the 17th floor of the building under far and near-fault ground motions are comparatively plotted in Fig. 9. Frequency contents of displacement, velocity and acceleration obtained from the initial and the calibrated models under near and far-fault ground motions are observed to be compatible with each other.



a) 1999 Duzce earthquake b) 1979 Imperial Valley earthquake

Fig. 9.The time histories of the displacement, velocity and accelerations on the 17th floor

4. CONCLUSIONS

The paper investigates the effect of ambient vibration based model updating effects on a tall RC building under far and near-fault earthquake motions. The results obtained from the study are summarized below:

- Approximately 43% difference between the initial analytical and experimental natural frequencies of the building for the first three modes is observed. After model calibrating, the differences between calculated and experimental natural frequencies are reduced to approximately 3%. It is also observed that calibrated analytical and experimental mode shapes have a close harmony.
- Differences between displacements obtained from the initial and the calibrated models along the height of the building under the near fault ground motion are bigger than those of the far-fault ground motion.
- The displacements, velocities and accelerations calculated from the calibrated model for near-fault ground motion are generally larger than those of the initial model. However, it is observed opposite situation for the far-fault ground motion.
- Frequency contents of the displacement, velocity and accelerations obtained from the initial and the calibrated models are generally compatible with each other.

It can be generally said that the effects of finite element model updating and near-fault ground motion in the assessment of tall RC buildings must be taken into account.

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