ESTIMATION OF DYNAMIC CHARACTERISTICS OF EXISTING COMMON REINFORCED CONCRETE BUILDINGS IN EGYPT USING AMBIENT VIBRATION TESTS

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ABSTRACT:

Experimental Modal Analysis (EMA) has grown steadily since the advent of the digital FFT spectrum analyzer in the early seventies. Nowadays, it provides a fast and economical technique for studying the dynamic behavior of real full-scale structures. In this paper, this approach has been utilized to evaluate the finite element (FE) results in order to achieve the modeling update that will lead to have a full-scale simulation between the mathematical model and the actual structure. Four studied cases of existing reinforced concrete buildings commonly used in Egypt have been chosen and examined by an accelerograph in order to extract the corresponding natural frequencies and mode shapes. In addition, a 3D FE model for each case was created and its results were compared with previous extracted data by taking into consideration two affecting factors of the materials used in these structures. These are the concrete strength and the brick Young's modulus. The process of modeling update was suggested for each case and a number of conclusions and recommendations are given.

KEYWORDS: Ambient vibrations, testing, RC buildings, Egypt

1. INTRODUCTION

Modal testing is a dynamic process in which the input data are the actual records for the response of a specific structure (displacements, velocities, and accelerations), and the output of this process are the dynamic characteristics for this structure. In the last few decades, structural engineers depended on the finite element (FE) analysis to extract the dynamic characteristics of buildings. Although there are many uncertainties concerning some properties of the considered building the FE method is still very popular for its simplicity in use and speed of calculation. The modal testing, sometimes called modal analysis, is considered the best solution for this problem as it measures the required characteristics on the actual state without any approximation or modification in the current building structure [1-2].

This paper focuses on addressing two key issues. The first is the application of experimental modal analysis based on ambient vibration testing (AVT) of a certain class of buildings in Egypt. These are skeletal reinforced concrete buildings having 3 to 6 stories which represent the most common type of buildings. The second main key issue is the finite element model updating for such buildings.

2. EXPERIMENTAL PROGRAM

The study has been performed on four different buildings located in different locations in Cairo. The first one has six stories and located in Manshyet Nasser area, the second building is located in 15 May city and has three stories and a basement, the third one is in Eltagamoa Elkhames city having three stories and a basement, and the last one is in 15 May city with five stories.

The ambient vibration response of the buildings was measured using the Kinemetrics Altus K2 Strong Motion Accelerogragh [3]. Twelve channels have been distributed on different floors in the two perpendicular directions (longitudinal and transversal).

The modal analysis step has been performed through two approaches. The first approach is to use the software package of the K2 Accelerograph. The second approach is the use of another separate program package; i.e., the Ambient Response Testing and Modal Identification Software (ARTeMIS) [4]. The later package gives both the natural frequencies and the corresponding mode shapes.

2.1 The Studied Cases

Four cases within Cairo City have been chosen to achieve the first objective of the present study. The twelve available channels of the accelerograph have been used in order to perform the modal testing process.

2.1.1 Case 1

The first study case is a complete 6-stories reinforced concrete building without basement, and this building is located in Cairo in the district of Eldeweka- Manshyet Nasser, figure 1 (a). The sensors were placed on the first, third and the last floors in the building two perpendicular directions. Ambient vibrations were measured for 5, 90, and 480 seconds.

2.1.2 Case 2

The second case in this study is a non-complete 3-stories reinforced concrete building with basement, and this building was located in 15 May city - Elemtedad., figure 1 (b). The sensors were placed on the first and third floors in the two perpendicular directions of the building. The duration of the measured file was 75 seconds.

2.1.3 Case 3

The third case is a complete 3-stories reinforced concrete building with basement, and this building was located in Eltagamoa Elkhames city, figure 1 (c). The sensors have been placed on the first and third floors in the two perpendicular directions of the building. The measured file had a duration of 85 sec.

2.1.4 Case 4

The last case is a complete 5-stories reinforced concrete building without basement, and this building was located in 15 May City, figure 1 (d). The sensors were placed on the ground, the third and the roof floors in the two perpendicular directions of the building. This building was tested during an explosion in an adjacent quarry cement factory. The measured file was 90 sec. duration. The first 30 sec. represents the response within the explosion interval , i.e., a forced vibration test. The remaining 60 sec. represents an ambient motion record.

3. TEST RESULTS

3.1 Results Using SMSP

The Strong Motion Software Package (SMSP) associated with the K2 accelerograph has been used to perform the instrument correction, filtering, and base line correction to eliminate the mechanical and electrical noise from the output to recover the corrected acceleration, velocity , displacement, and their Fourier Amplitude and response spectra. Figure 2 shows a sample of the Fourier response in the longitudinal direction of the Study Case 1 for two different file durations.

(a) case number 1

(b) case number 2

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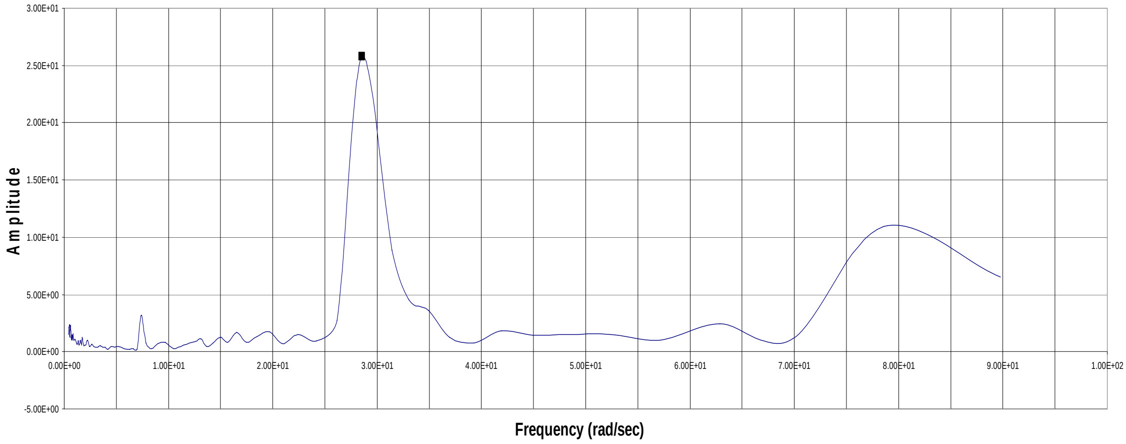
(c) case number 3

(d) case number 4

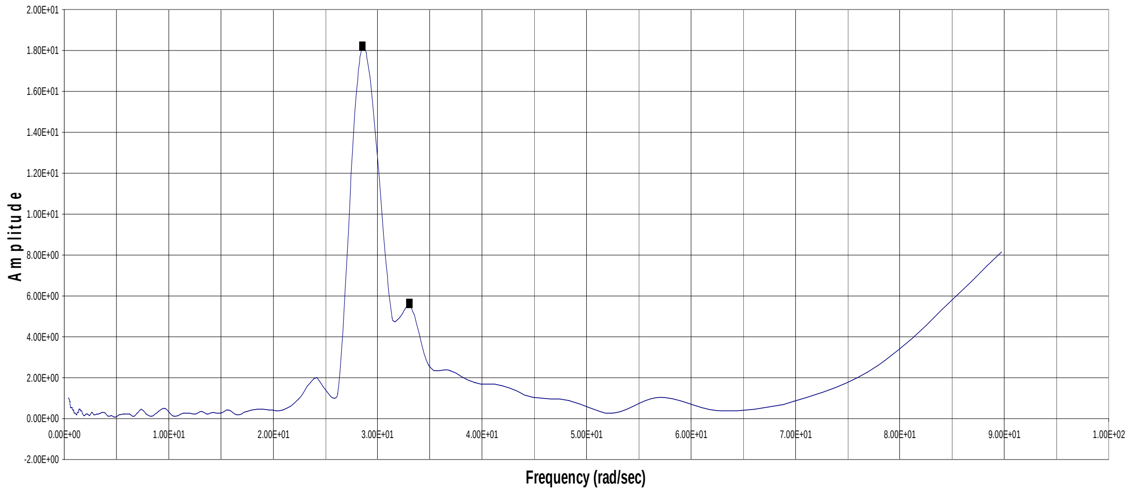
Figure 1 General view of tested buildings

3.2 Results Using ARTeMIS

The recorded ambient vibrations have been used as input for the ARTeMIS program and the resulting frequencies agreed well with those obtained by using the SMSP program for all Study Cases. Moreover, the corresponding mode shapes have been obtained. Figure 3 shows an example for the obtained mode shapes for Study Case 1.



(a) File 5 sec. duration (Peak: 28.56 rad. / sec.)



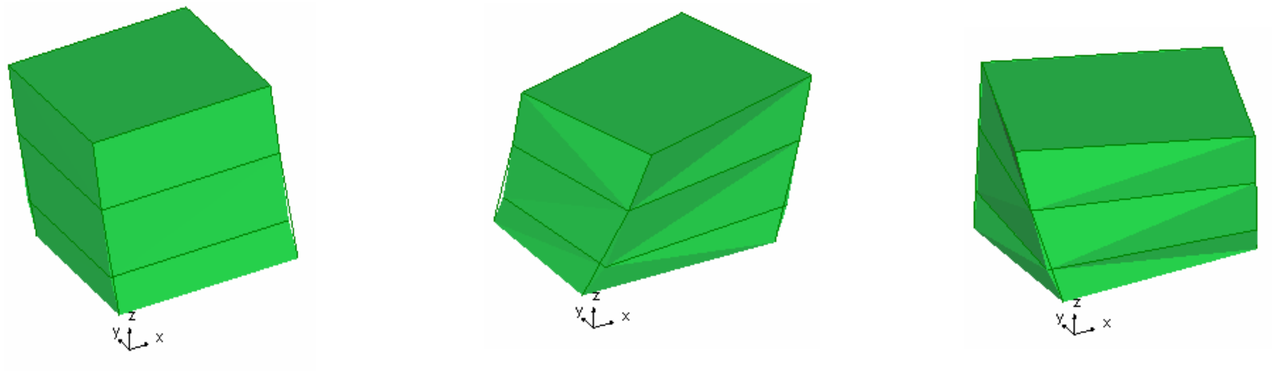
(b) File 90 sec. duration (Peaks: 28.56 and 33.1 rad. / sec.)

Figure 2 The Fourier response in the longitudinal direction for Study Case 1

4. FINITE ELEMENT ANALYSIS

A finite element analysis was performed using the computer program SAP2000 [5], and a three- dimensional model was used for the dynamic modal analysis in order to obtain the fundamental frequencies and mode shapes. Two main factors have been taken into consideration in this analysis. The first factor is the Young's modulus for concrete (E_c) which depends on the value of concrete strength (f_{cu}) [6] and usually varies between 200 – 300 kg /cm^2. The second factor is the Young's modulus for bricks (E_b) which varies from 6 – 20 ton / cm^2 based on the designer point of view.

Since it was not possible to know the real values of f_{cu} for concrete elements and E_b for masonry, one has to assume different values for these two parameters to explore their effect on the dynamic characteristics of studied buildings. The values chosen for the concrete strength f_{cu} are 200, 250, and 300 kg/cm^2, and the values chosen



Mode # 1 = 0.22 sec   Mode # 2 = 0.24 sec   Mode # 3 = 0.19 sec

Figure 3 Mode shapes obtained by ARTeMIS program for Study Case 1

for the brick Young's modulus E_b are 6, 12, 20 ton/cm^2 . Therefore, nine different results have been obtained for each study case. Table 1 shows an example for the Study Case 1.

One can see from the shown results that the Eigenvalues are decreasing with the increase of the value of f_{cu}, if E_b is constant. In addition, the Eigenvalues are also decreasing with the increase of the value of E_b, if f_{cu} is constant. This can be explained by the fact that the more rigid the structure is the smaller period the structure will have.

Table 1 Results by finite element analysis of Study Case 1

Analysis No.	f_{cu} kg/cm^2	E_b ton/cm^2	Mode 1 Period (sec.)	Mode 2 Period (sec.)	Mode 3 Period (sec.)
1	200	6	0.424 (long.)	0.422 (trans.)	0.413 (tor.)
2	200	12	0.343 (long.)	0.337 (trans.)	0,327 (tor.)
3	200	20	0.291 (long.)	0.283 (trans.)	0.269 (tor.)
4	250	6	0.417 (long.)	0.413 (trans.)	0.405 (tor.)
5	250	12	0.337 (long.)	0.332 (trans.)	0.322 (tor.)
6	250	20	0.286 (long.)	0.279(trans.)	0.266 (tor.)
7	300	6	0.407 (long.)	0.401(trans.)	0.395 (tor.)
8	300	12	0.329 (long.)	0.325 (trans.)	0.316 (tor.)
9	300	20	0.280 (long.)	0.274 (trans.)	0.262 (tor.)

5. COMPARISON BETWEEN EXPERIMENTAL AND THEORETICAL RESULTS

Now it is possible to compare the experimental results with the theoretical ones obtained by the FEM in order to explore the percentage of error between them. This will enable the update of the theoretical model, which is the second objective of the paper. As an example, for Study Case 3 Table 2 shows the change in the percentage of error with the change of the characteristics f_{cu} and E_b. In addition, one can see that the best modification for the previous characteristics here in this case is to have f_{cu} equal to 200 kg/cm^2 and E_b equal to 6 ton/cm^2 , which correspond to the least percentage of error.

Table 2 Comparison of results for Study Case 3

Mode	E_b t/cm^2	Period (sec.)						
		Experimental Value	Theoretical Values					
			f_{cu} kg/cm^2					
			200	Error %	250	Error %	300	Error %
1 st	6	0.400	0.394	**1.5**	0.387	3.4	0.378	5.8
	12		0.294	36.1	0.289	38.4	0.284	40.8
	20		0.252	58.7	0.247	61.9	0.241	66.0
2 nd	6	0.395	0.364	**8.5**	0.355	11.3	0.344	14.8
	12		0.287	37.6	0.282	40.1	0.275	43.6
	20		0.238	66.0	0.236	67.4	0.232	70.3
3 rd	6	0.339	0.315	**7.6**	0.309	9.7	0.3	13.0
	12		0.232	46.1	0.230	47.4	0.226	50.0
	20		0.190	78.4	0.188	80.3	0.186	82.3

Similarly, one can obtain the values for f_{cu} and E_b that produce the least percentage of errors in other Study Cases. Table 3 summarizes these results.

Table 3 Summary of best characteristic values for all Study Cases

Study Case	Mode	Best Characteristic Values		
		f_{cu} kg/cm^2	E_b t/cm^2	Error %
1	First	300	20	14.3
	Second			19.7
	Third			27.5
2	First	300	20	21.3
	Second			23.1
	Third			12.6
3	First	200	6	1.5
	Second			8.5
	Third			7.6
4	First	300	12	0.4
	Second			4.5
	Third			11.1

6. Comparison with the Egyptian Code formula

Now it is possible to compare the experimental values of the fundamental natural period with the Egyptian code formula for the RC buildings [6]:

$$T = 0.1\ N \qquad (1)$$

where T is the fundamental natural period in seconds, and N is the number of floors.

Table 4 shows such comparison where it is clear that the Egyptian seismic code formula gives non-accurate values for the fundamental period of vibration in all cases, except for only one case. Therefore, this formula needs some corrections in order to be applicable for all cases of RC buildings in Egypt.

Table 4 Comparison between the experimental values and the Egyptian code formula

Study Case	Building Description	Actual measured fundamental Period (sec)	Code formula fundamental Period (sec)	% Error
1	complete	0.24	0.60	150%
2	Non-Complete	0.24	0.40	66.7%
3	complete	0.40	0.40	0%
4	complete	0.26	0.50	92%

7. Conclusions

Based upon the results of this research the following points can be concluded:

1. Minimum record duration during the experimental test should not be less than 60 sec. in order to ensure covering at least the first three modes of vibration.
2. The value of Young's modulus of walls (E_b) is a very important factor in the evaluation process as the change in assuming this parameter within the common range may lead to a difference in the results of about 40 %.
3. The value of concrete strength (f_{cu}) is not an important factor in the evaluation process as the change in assuming this parameter within the common range may lead to a difference in results not exceeding 10%.
4. Each structure is unique in the modeling update process as each study case has different modified values for E_b and f_{cu}.
5. The proposed formula in the Egyptian code for the fundamental period of buildings is not a reliable formula since it leads to values larger than that obtained from the experimental measured ones.

8. References

1. Mendoza. L., Reyes, A., Eeri, M., and Luco, J. E., (1991), Ambient vibration tests of the Mexicali general hospital, Earthquake Spectra 7, 281-300.

2. Bertrand, E., Duval, A.M., and Vidal, S., (2006), Dynamic response assessment of building from microtremor measurments in Guadeloupe, France, First European Conference on Earthquake Engineering and Seismology, Paper No. 177.

3. Altus K2 Strong Motion Accelerograph, Kinemtrics, Inc., Pasadena, California, U.S.A.

4. Operational Modal Analysis Tools, ARTeMIS, (2007), Structural Vibration Solutions Company A/S, Denmark.

5. SAP2000, Static and Dynamic Finite Element Analysis of Structures, Version 7.42, (2001), Computers and Structures, Inc., Berkeley, California, U.S.A.

6. Egyptian Code for the Design and Construction of Reiforced Concrete Structures, (2001), National Center for Building Research and Urban Planning, Giza, Egypt.