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AMBIENT VIBRATION EXPERIMENTAL TESTING TO EVALUATE SEISMIC DAMAGE

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ABSTRACT

The results of ambient vibration testing are frequently used to calibrate numerical models for existing buildings, to evaluate the dynamic characteristics of buildings before and after a seismic rehabilitation, and to identify soil-structural interaction effects. Seismic response of buildings and damage detection are also obtained. This paper presents the results of ambient vibrations measurements performed to estimate frequencies of buildings and soil in Boumerdes city (Algeria), after the Zemmouri earthquake on 2003. Similar experimental tests were performed on RC buildings in Algiers city, before and after the 2003 earthquake. Results of both experimentation tests are discussed in this study.

INTRODUCTION

Seismic vulnerability represents the possibility of damage or loss of buildings in relation to a seismic event. Some methods to evaluate the vulnerability are based on the analysis of the building by using simple analytical models. Other methods use expressions for fundamental period calculation. Most of the codes, such as the Uniform Building Code, the Euro Code (EC8) and the Algerian Seismic Code (RPA), propose simplified empirical formulas to estimate the fundamental period in the field of the small deformations. However, the fundamental periods obtained are generally not error free. These errors come from the difference between theoretically modelled and the real structure on the one hand, and the damages undergone by the existing building during its occupancy, on the other hand.

Fundamental periods are also obtained using on site experimental testing. Among the experimental testing methods, ambient vibration testing is frequently used to identify the modal parameters of an existing structure for the seismic vulnerability analysis. In last decades, many researchers have focused their studies on numerical and experimental investigation to estimate the dynamic characteristics, particularly the fundamental frequency of both damaged and undamaged buildings during past earthquake (Clotaire and Guéguen 2007, Dunand et al. 2004). Other studies have compared the fundamental frequency obtained using experimental testing and that calculated using empirical formulas given by the seismic codes (Ait meziane et al. 2012).

Results of various studies have confirmed the strong difference between experimental period values and those obtained using empirical expressions provided by design codes. It was confirmed in various studies that; (i) the assessment of dynamics characteristics of existing building is a complex issue, due to the inevitable uncertainness regarding mechanical proprieties of materials, effects of past loading referring to service and accidental loads; (ii) the original mechanical proprieties of the building materiel often have been modified by the age, the environmental effects over time, that

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conduct to the fatigue phenomena. Despite these uncertainties, the ambient vibration testing became useful to evaluate the dynamic characteristics of buildings and the soil-structural interaction effects.

This paper presents the results of ambient vibrations measurements performed to estimate the frequencies of reinforced concrete buildings and soil in Boumerdes city (Algeria), after the 21 May, 2003 earthquake. The selected buildings have suffered damage degrees 1 and 2, according to the damage classification of the European Macroseismic Scale EMS-98 (Grunthal 1998). So they were classified as undamaged or very slightly damaged buildings during the post-earthquake investigation. The selected buildings in Algiers are reinforced concrete and have been classified also as undamaged or very slightly damaged following the earthquake.

CASE STUDY

About 80% of buildings in the urban area of Boumerdes city are Reinforced Concrete (RC) structures, built during the period between 1969 and 2003. The structural system is composed of columns and beams (frame) and/or shear walls. Buildings with frame system are mainly; (i) those built before 1980 (prior to the first seismic code) without seismic resistant design, and (ii) private no engineering buildings built after 1980. Before the 2003 Zemmouri earthquake, the seismic design code was not applied to private buildings. The 2003 earthquake has evidenced that the widely used system of construction has proven to be highly vulnerable; over 80% of the buildings were destroyed or heavily damaged in the epicenter area were RC frame structures with infill masonry walls (Figures 1 and 2). Some particular conditions such as: soft stories, undersized sections, insufficient longitudinal reinforcement, and weak concrete strength have been shown to be the cause of the majority of earthquake damage in no engineering buildings (Belazougui 2008).

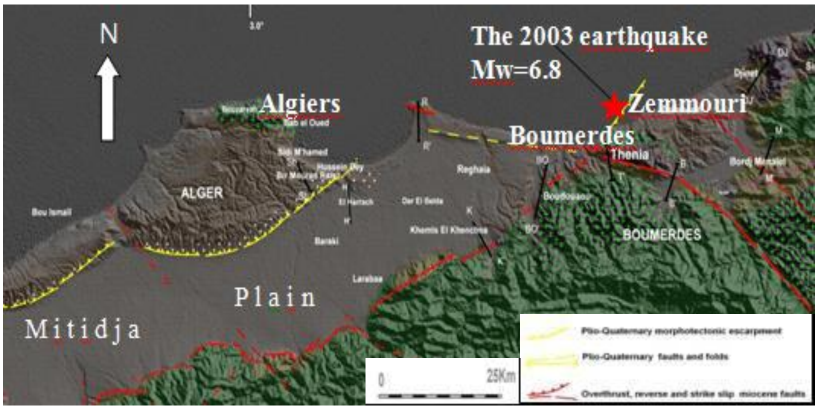

Figure1.Characteristics of Zemmouri earthquake of 21 May 2003

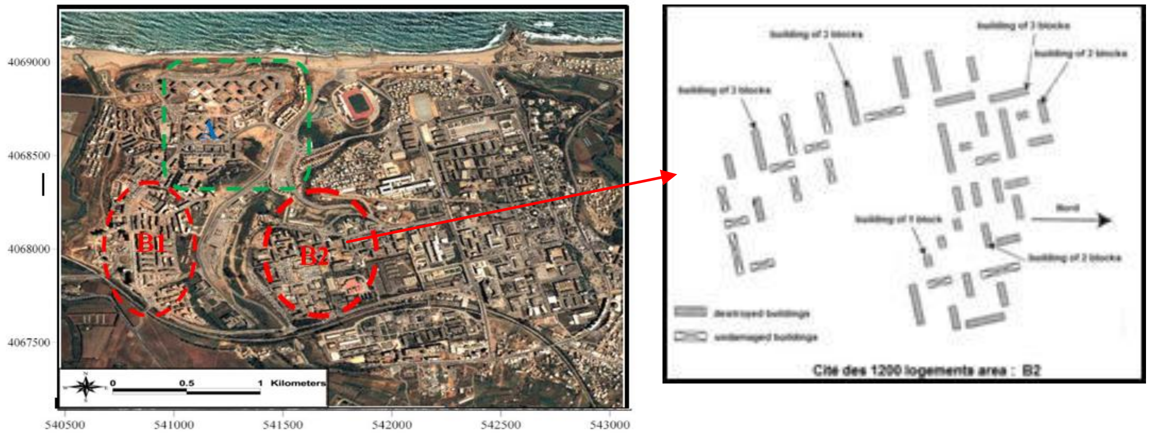

Figure 2. View of Boumerdes city with location of damaged buildings during the 2003 earthquake

MEASUREMENTS PROCEDURE AND DATA COLLECTION

In this study, the ambient vibration testing is used to identify the fundamental frequency of the selected existing buildings. The ambient vibration H/V method (H/V: horizontal to vertical ratio) (Sesame 2005) is now widely used to estimate frequencies of buildings and soils, and has proven to be a good tool for site effect evaluation (Khalil et al. 2007, Nakamura 1989).

Following the 2003 earthquake, the ambient vibration testing has been conducted in Boumerdes city, including slightly damaged buildings and soil. Typical RC frame buildings composed of two blocks (2B) and three blocks (3B) were selected in the *Cité 1200 logements* (zone B2) (Figures 2 and 3). Also, typical RC shear wall buildings composed of one block were selected in the *Cité 800 logements* (zone A) (Figures 2 and 3). In the experimentation test, the response measurements of each building to the background noise lasted for 30 min. The Cityshark II and the Lennartz 3d-5 s sensors developed by Chatelain et al. (2000) are used. The fundamental frequency of resonance of each building was then identified using the Geopsy Software developed by Wathelet (Sesame 2005). The signal analysis is made using the comparison technique of two amplitude durations, an average of short duration (Short Time Average-STA) and an average of long duration (Long Time Average-LTA) of about 30 s whose value is not very sensitive to the amplitude variations. A 30-s response duration windows without transient noise (anti-trigger STA/LTA) are used. A window is considered stable when STA/LTA ratio lies between 0.5 and 2. The spectral amplitude for each stabilized window is calculated using the Fourier transform. In order to identify the fundamental frequency of the structure, the last floor was selected to record the response. The natural frequencies of the tested building are then identified from the frequency spectrum. The results obtained are presented in Tables 1 and 3.

In zone A, the majority of existing buildings are RC shear walls. For the five-story RC shear wall buildings natural frequencies values are ranging between 4.3 Hz and 4Hz, and for the ten-story RC shear wall buildings natural frequencies values are ranging between 2.2 Hz and 2.1 Hz. This category has suffered a very slight damage. The five-story (mid-rise) RC frame buildings are located in zone B2; they are public buildings built prior to the first seismic code RPA81 (CTC 1981). For this category, frequencies values are ranging between 3.0 Hz and 3.4Hz for buildings with two blocks (2B), and between 3.4 Hz and 3.5% Hz for buildings with three blocks (3B). In zone B1 there are private no engineering buildings for which the seismic code was not enforced. They were extensively damaged in the 2003 earthquake. Experimental testing was not performed for this category of buildings.

Similar experimental tests were performed on RC buildings in Algiers city, before and after the 2003 earthquake. The selected buildings were built in the period between 1949-1554 (Figure 4). The buildings are 13, 14, 15 and 16 stories high and their resisting system consists of frames (columns and beams) and RC walls. These buildings also suffered no structural damage (degree 1 and 2). The results obtained as presented in Table 3, reveal a significant decrease of frequencies recorded before and after the earthquake.

Figure 3. Building of three blocks in *Cité 1200 logements* (left),
Building of 10 stories in *Cité 800 logements* (right)

Table 1. Experimental frequency of 5 story-buildings of the *Cité 1200 logements*

RC frame buildings	EMS-98 damage grade	Frequency (Hz)	
		Longitudinal	Transversal
1200 (2Blocks)	Grade1 and 2	3.0	3.4
1200 (3Blocks)	Grade1 and 2	3.4	3.5

Table 2. Experimental frequency of 5 and 10 Story-Buildings of the *Cité 800 logements*

RC shear wall buildings	EMS-98 damage grade	Frequency (Hz)	
		Longitudinal	Transversal
5 stories	Grade1 and 2	4.3	4
10 stories	Grade1 and 2	2.2	2.1

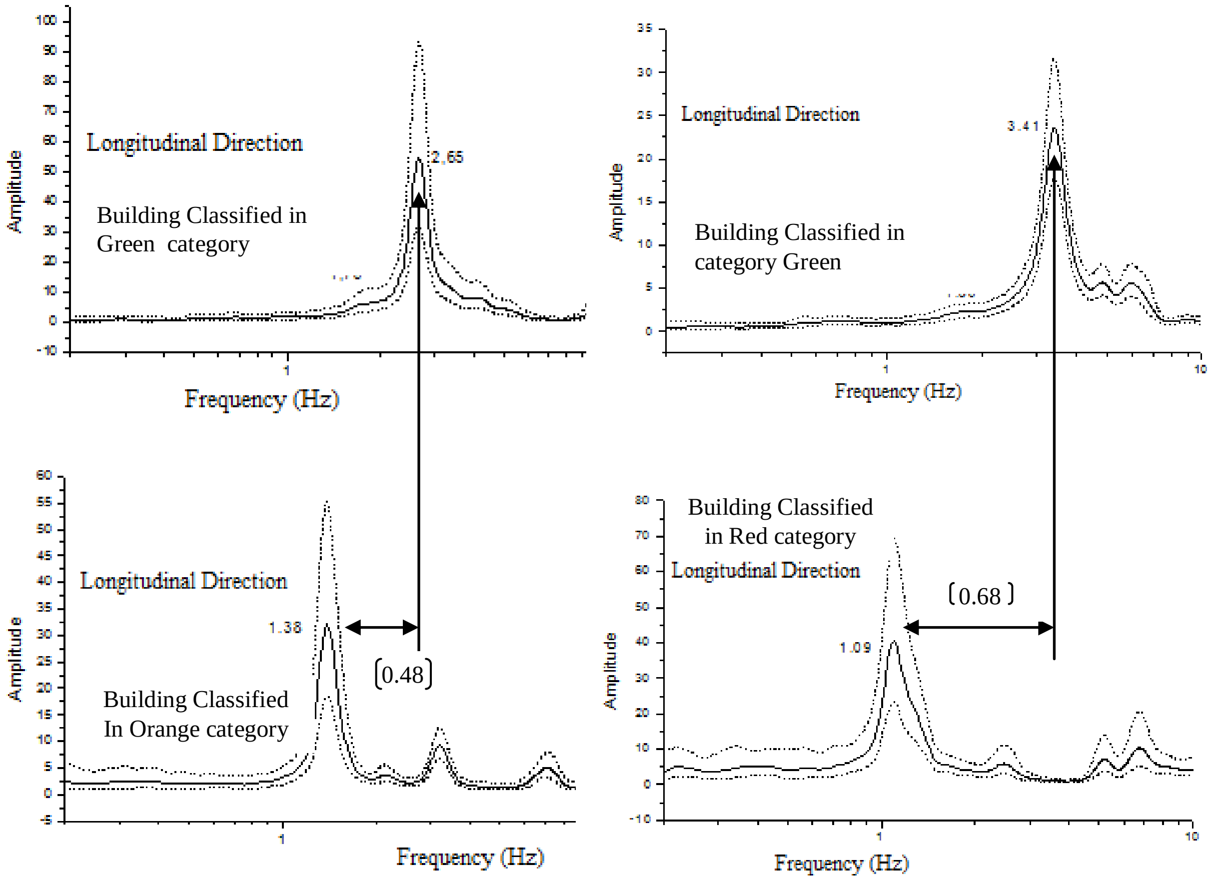

Figure 4. Spectral response of buildings in *Cité 1200 logements*
(left : buildings of two blocks, right :buildings of three blocks)

Figure 5: Reinforced concrete buildings (1949 – 1954 period)

Table 3. Experimental frequencies of buildings before and after the 2003 earthquake

Buildings	Experimental frequencies (Hz)			
	Before 2003		After 2003	
	Longitudinal	Transversal	Longitudinal	Transversal
13 stories	1.62	1.12	1.36	1.05
14 stories	2.07	1.53	1.99	1.45
15 stories	1.67	1.22	1.48	1.17
16 stories	1.1	1.2	1	1.02
16 stories	1.85	1.42	1.35	1.24

SOIL CONDITIONS AND SITE RESPONSE

The procedure of ambient vibration experimental testing was used to determine the fundamental frequency of soil. Soil in zones A, B1 and B2 in Boumerdes city (Figure 2) is composed essentially of granulitic mica schist formations (hard soil) as substratum at about 118 m to 141 m deep (Scandinavian Engineering Corporation 1970). These formations are overlain by preconsolidated marl (hard to stiff soil) at about 27m to 37 m deep. In zone A, in the northern part, the preconsolidated marl is overlain by red sands, recent clays, beach sands and Quaternary dune sands (soft deposits). The experimental results of ambient vibration testing show that the fundamental frequencies of the soil in all zones are ranging between 0.8 Hz and 1.2 Hz.

EMPIRICAL FREQUENCIES

Fundamental period of the building can be obtained using empirical formulas given by the seismic codes. Generally, these formulas are depending on the dimensions in plan and in elevation of the building (CEN 2004, NZSEE 2006, CGS 2003). In the Algerian seismic code (RPA 99 version 2003) (CGS 2003) two empirical expressions are given; (1) and (2) to calculate the fundamental period. Eq. 1 is depending on the structural system type and the walls filling density. Eq. 2 uses the building height and the plan dimensions.

$$T = C_t h_N{}^{\alpha} \quad (1)$$

$$T = \frac{0.09 h_N}{\sqrt{D}} \quad (2)$$

The seismic codes proposes different values for the coefficient C_t and α for different building structural typologies. In the Algerian seismic code, α is equal to 0.75 for all structural system types. There are three values for the coefficient C_t; 0.05, 0.075 and 0.08, depending on the structural system type and the walls filling density. h_N is the total height of the building and D is the plan dimension of the building (see Table 4). Using the empirical formulas (1) and (2), fundamental frequencies of the selected buildings are obtained, as shown in Table 5. The estimation of the building frequencies using both formulas shows that differences are noticeable. Differences are also visible between the experimental and the empirical frequencies values according to Tables 3 and 5.

Table 4. Buildings dimensions

Location	Height (m)	Length (m)	Width (m)
13 Stories	39	24.5	8.10
14 Stories	42	40	10.5
15 Stories	45	44	10.5
16 Stories	48	33.2	24.5
16 Stories	48	40	10.7

It is clear that for the five buildings tested in Algiers district before the 2003 earthquake event, the fundamental frequency has undergone a decrease after the seismic event. However, the values of the frequencies obtained experimentally are lower than those obtained by empirical calculation.

Table 5: Empirical frequencies of buildings required by seismic Algerian codes

Buildings	Empirical frequencies		
	$F = 1/C_t h_N^{\alpha}$	$F = 1/\frac{0.09 h_N}{\sqrt{D}}$	
		Longitudinal	Transversal
13 stories	1.28	1.41	0.81
14 Stories	1.21	1.75	0.83
15 Stories	1.15	1.64	0.8
16 Stories	1.09	1.33	1.14
16 Stories	1.09	1.47	0.756

CONCLUSIONS AND DISCUSSION

The results of post earthquake investigations show that a majority of damaged buildings in Boumerdes city after the 2003 earthquake were mostly mid-rise RC frame structures. The buildings selected in the study have suffered damage degrees 1 and 2 and have been considered as undamaged or slightly damaged during the field investigation following the earthquake. According to the definitions of the EMS-98 Scale (Grunthal 1998), degree 1 corresponds to negligible to slight damage (no structural and slight non-structural damage). Degree 2 corresponds to moderate damage (slight structural and moderate non-structural damage). This classification does not consider the state of degradation of the building before the seismic event.

The H/V ratios obtained by the ambient vibration testing did not show probable soil-structural interaction. In fact, the ranges of frequencies of all tested buildings in zones A, B1 and B2 (2.1 Hz to 4.3 Hz) are clearly different of those obtained for soil in these zones (0.8 Hz to 1.2 Hz). This result confirms the absence of soil-structural interaction and the resonance phenomena that play a significant role in building damage induced by earthquake. However, these results cannot be an indicator of damage, because the buildings have not been tested before the earthquake.

The experimental ambient vibration tests performed on RC buildings in Algiers city show a decrease in frequencies following the seismic event. These buildings were classified as undamaged during the post-earthquake investigation because there was no damage in the structural parts. However, the ambient vibration test revealed a decrease of the frequencies obtained before and after the event that can probably due to the non-structural damage on infill masonry walls. This result confirms also that the dynamic characteristics of buildings are also depending of the non-structural elements by the participation of the infill walls to the structure rigidity (Ait Meziane et al. 2012, Chaker and Cherifati 1999).

In the case of the tested buildings in Algiers, a comparison between the experimental and the theoretical frequencies was made on two ways. The first way is the comparison between the frequencies calculated according to the Algerian seismic code (RPA 99 version 2003) using empirical formulas and those experimentally identified of the buildings after the 2003 earthquake. The second way is the comparison between the frequencies calculated before and after the 2003 earthquake of the selected five buildings and those calculated according to the empirical formulas given by the code; (1) and (2). The formulas consider that the period of the building is proportional to the ratio of the height to the plan dimensions of the building in the direction of the solicitation.

The empirical formulas of the code are applicable to new buildings, considering their design. Their application to buildings built without seismic resistant design would certainly be prone to large uncertainties. The study shows that differences are clear between the experimental frequencies and those estimated using empirical formulas. The tests on the five buildings in Algiers before and after the 2003 earthquake show that the fundamental frequency has undergone a decrease after the seismic event. Consequently, the values of the frequencies obtained experimentally should be lower than those obtained by empirical calculation.

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