MICROTREMOR MEASUREMENTS FOR THE ESTIMATION OF SEISMIC RESPONSE IN BOUMERDES ALGERIA

Kimiro MEGURO[1] and Said ELKHOLY [2]

ABSTRACT: On May 21, 2003 a destructive, shallow earthquake of moment magnitude Mw =6.8 occurred in Boumerdes, a city located 50 km east of the capital city of Algeria and caused damage in five provinces in the north central part of the country. Nearly two months after the event, Japan Society of Civil Engineers (JSCE) dispatched a reconnaissance team to the damage site for post-earthquake investigation. As JSCE team members, we summarize important findings on the local site effects, and structural damage based on microtremor measurements. In this study Nakamura's technique is adopted since it allows a quick evaluation of site seismic response. The main advantage of this technique is that it does not require any information about geotechnical or geological properties of the soil deposit at the investigated site.

Key Words: earthquake damage, site effects, seismic hazard, microtremor measurements, Boumerdes Algeria.

INTRODUCTION

At 19:44 (local time) on May 21, 2003, a strong earthquake (Mw = 6.8) struck Boumerdes city in northern Algeria. The epicenter of the earthquake was located offshore at 39.91N-3.58E, 7 km north of Zemmouri in the Boumerdes city. According to the governmental report, the earthquake caused 2,278 deaths, more than 10,000 injured and approximately 180,000 homeless. This earthquake, as well as recent destructive earthquakes, have clearly illustrated that the near- surface geological and topographical conditions play a major role in determining the hazard level. The information on site seismic response, such as the mapping of predominant frequency and amplification of soil is very important to mitigate the casualties due to strong earthquakes. It can provide a useful guide to define the safety regions for reconstruction after destructive earthquakes.

In this paper, the results obtained during post-earthquake field investigation in Boumerdes city and surrounding areas are presented. The paper summarizes the findings on site seismic response and damage to engineering buildings based on microtremor measurements. Nakamura's technique was adopted since it allows a quick evaluation of site seismic response. The main advantage of this technique is that it does not require any information about geotechnical or geological properties of the soil deposit at the investigated site. Moreover, it considers a very fast and low cost method for pre- and post disaster surveys. The technique allows to estimate the site response (the predominant period and amplification factor) by means of the spectral ratio between horizontal (H), and vertical (V) components of microtremors registered at a single point (Nakamura, 1989), (Nakamura et al., 1995). This technique has been widely accepted to investigate site conditions (Field et al., 1995; Lermo et al., 1994; Lachet et al., 1994; Field et al., 1995).

In the case study of Boumerdes city, the methodology for seismic zoning is validated by comparing the soil characteristics and site effects obtained from microtremor measurements with the earthquake damage

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[1] Associated professor
[2] Ph. D Candidate

levels observed in the field survey. The results show a good correlation between damage levels and both sites amplification factors and predominant frequencies.

QUICK DETECTION OF SITE EFFECTS FROM MICROTREMOR MEASUREMENTS

Microtremors were measured in Boumerdes city to investigate the relation between structure damage level and local site effect. Nearly two months after the earthquake, microtremor measurements were conducted at sixteen different sites in Boumerdes city (G01-G16). **Figure** 1 shows the locations of the measurement points plotted on a post-event satellite image of Boumerdes city.

Measurement:

An instrument named Geophysical Data Acquisition System (GEODAS) made by Buttan Service Co. (Japan) was used for microtremor measurements. The natural period of the sensor is 2 s. with available frequency response range from 0.5 to 20 Hz. The sensor was set on the asphalt or the soil to simultaneously record two horizontal components (NS and EW directions) and a vertical component. At each point, four to five 40.96 s microtremor measurements were taken with a sampling frequency of 100 Hz.

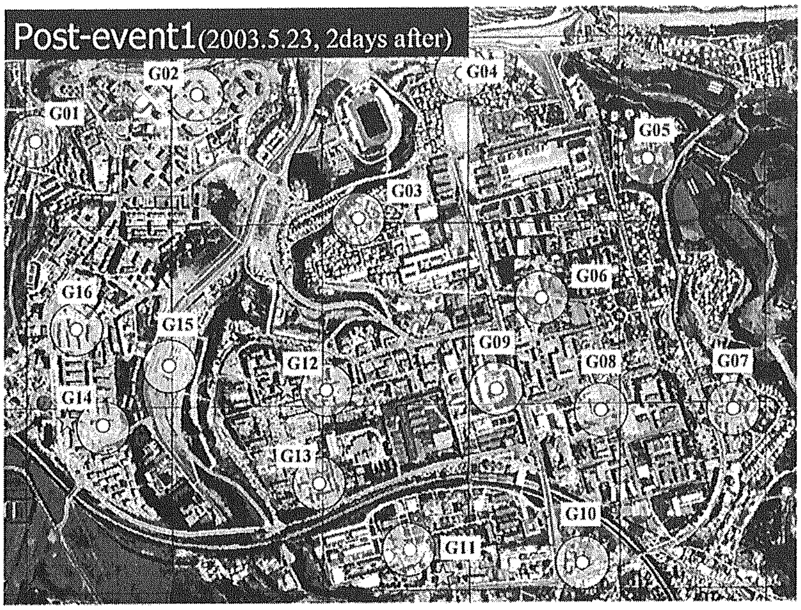


Figure 1 Locations of microtremor observation points and inspected buildings (☆)

Analysis:

The portions of the record with strong, local impulsive sources, such as traffic, were eliminated. The remaining portions were divided into windows of 2048 samples each and their spectra were calculated after correcting the baseline. The spectrum of one component was estimated by averaging three Fourier spectra. Then, the Quasi-Transfer Spectrum (QTS) was calculated from the spectral ratio of horizontal to vertical components according to Nakamura (1995). The group of spectral ratios was used to determine the soil deposit dynamic characteristics, namely the predominant frequency (F) and amplification factor (A). Frequency range between 0.5 to 20Hz is discussed here because it corresponds to the instrument measuring frequency range.

Results:

Figures 2 and 3 show the horizontal to vertical spectral ratios at the longitudinal (NS) and transversal (EW)

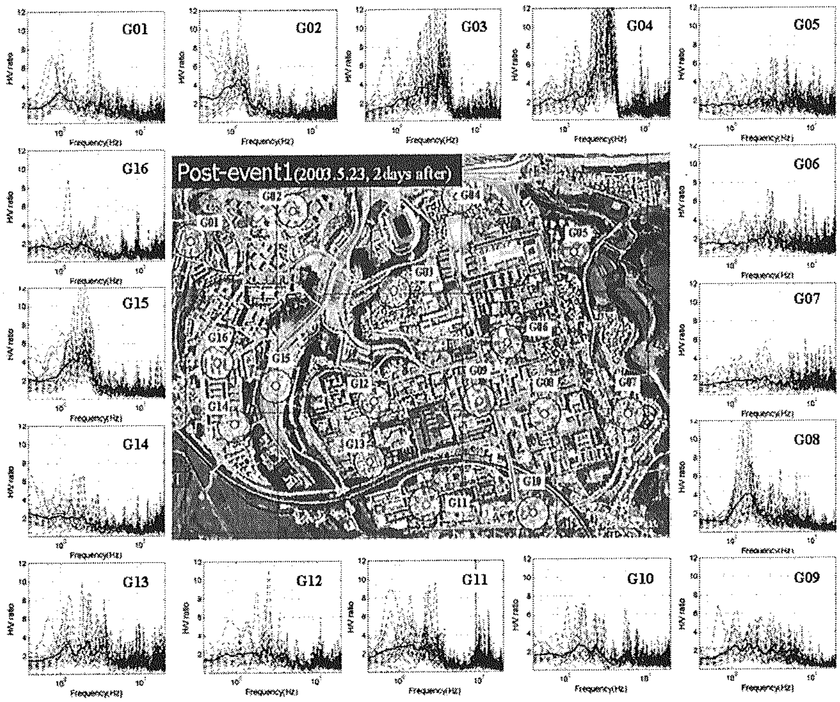


Figure 2: H/V spectral ratio (NS component) of the microtremor measurements

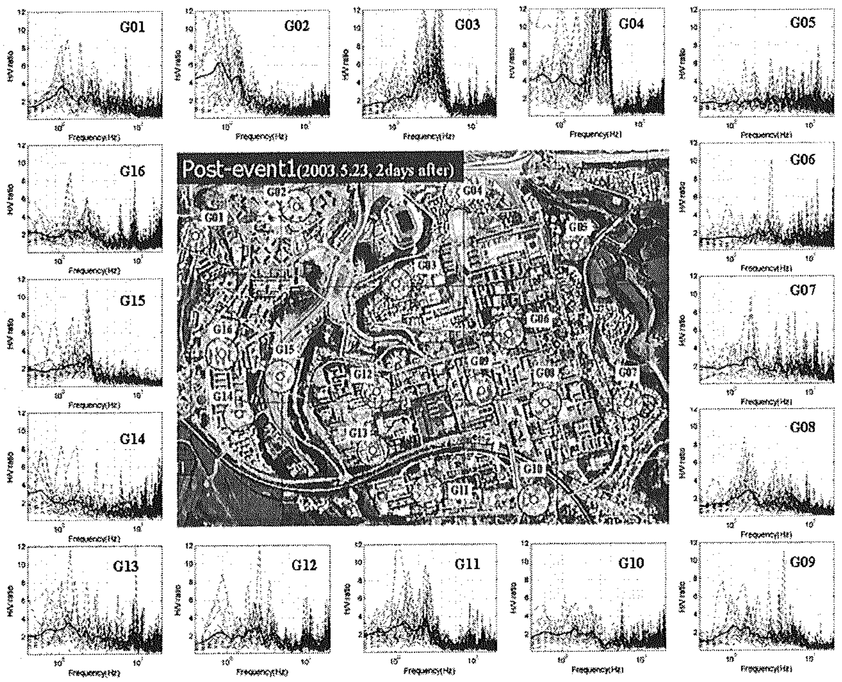


Figure 3: H/V spectral ratio (EW component) of the microtremor measurements

directions. In both figures, the thin black curves correspond to a single measurement whereas the thick curves represent the average of all measurements. These figures show the large variation in both predominant frequency (F) and amplification factor (A). **Table 1** lists the predominant frequency and amplification factor of the sixteen observation points.

Figure 4 shows the measurements at sites G02, G03, G04, G08, G13, and G15, which present a rather high amplification factor thus indicating a poor soil condition. The influence of the surface topography was also noted at some observation points like G02, G04, and G15. The changes in the frequency and amplitude of H/V spectrum ratios at those points may be explained by the variation of the topography of the measured points at the measurement directions.

Table 1 Dynamic characteristics of the soil deposit at observation locations

Site Name	NS component		EW component		Soil type
	(F) Frequency (Hz)	(A) Maximum H/V	(F) Frequency (Hz)	(A) Maximum H/V	
G01	1.00	3.40	1.10	3.80	Medium
G02	1.06	4.50	0.85	6.20	Bad
G03	3.50	5.00	1.8~4.00	5.8	Bad
G04	1.00~4.00	11.00	1.60~3.80	11.8	Bad
G05	5.00	2.80	flat	2.80	Good
G06	Flat	2.80	flat	2.20	Good
G07	Flat	2.00	1.50~2.00	3.00	Good
G08	1.00~2.00	4.00	0.90~2.00	3.00	Bad
G09	2.00	2.20	1.00~5.00	2.20	Good
G10	1.10~2.3	3.00	flat	2.70	Good
G11	1.10~2.50	3.75	1.00~3.00	3.75	Medium
G12	Flat	2.80	0.80~1.50	3.00	Medium
G13	1.00~3.50	3.50	0.50~2.50	3.80	Bad
G14	0.40	3.00	Flat	3.70	Medium
G15	1.00~2.5	5.00	1.00~2.50	3.80	Bad
G16	Flat	2.20	flat	2.50	Good

Figure 5 shows spectral ratios at G05, G06, G07, G09, G10, and G16, sites with good soil condition. At these locations, the H/V spectrum ratio is almost flat and the average maximum amplification factor is approximately two.

Figure 6 shows the distribution of soil conditions based on the microtremor observations. The figure shows how hazard levels may vary inside wide municipal territories. In order to verify the ability of microtremor measurements to characterize site effects, the site parameters obtained from microtremor measurements were compared with the earthquake damage levels observed in the field survey. Generally, the locations with poor soil conditions exhibited the severest structural damage. Thus, it can be concluded that the local site amplification factors obtained through microtremor measurements can be used to determine the expected seismic hazard levels.

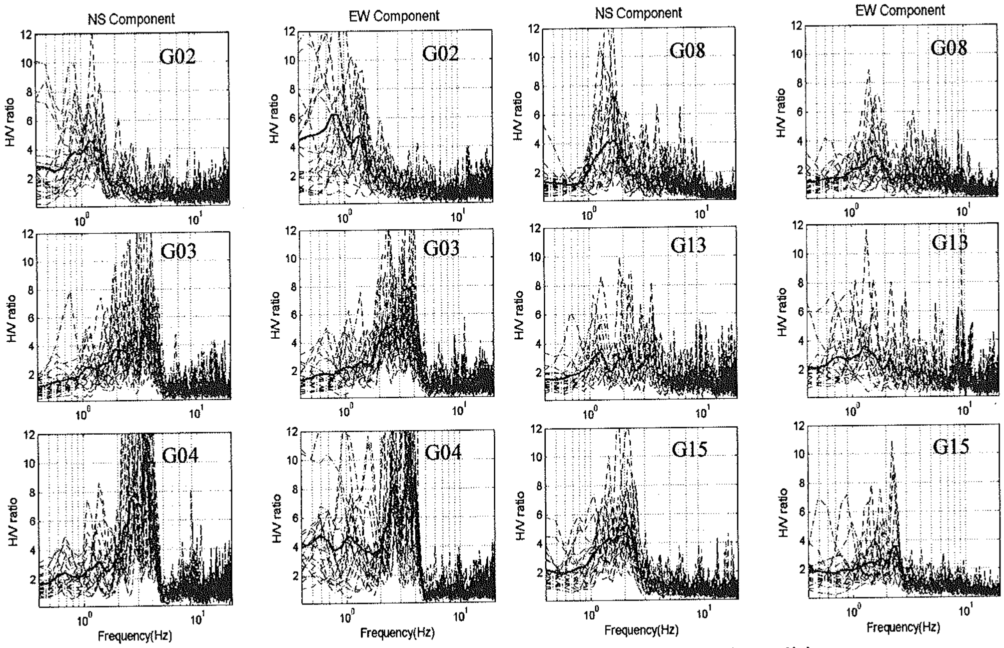


Figure 4: H/V spectral ratios at the sites with poor soil conditions

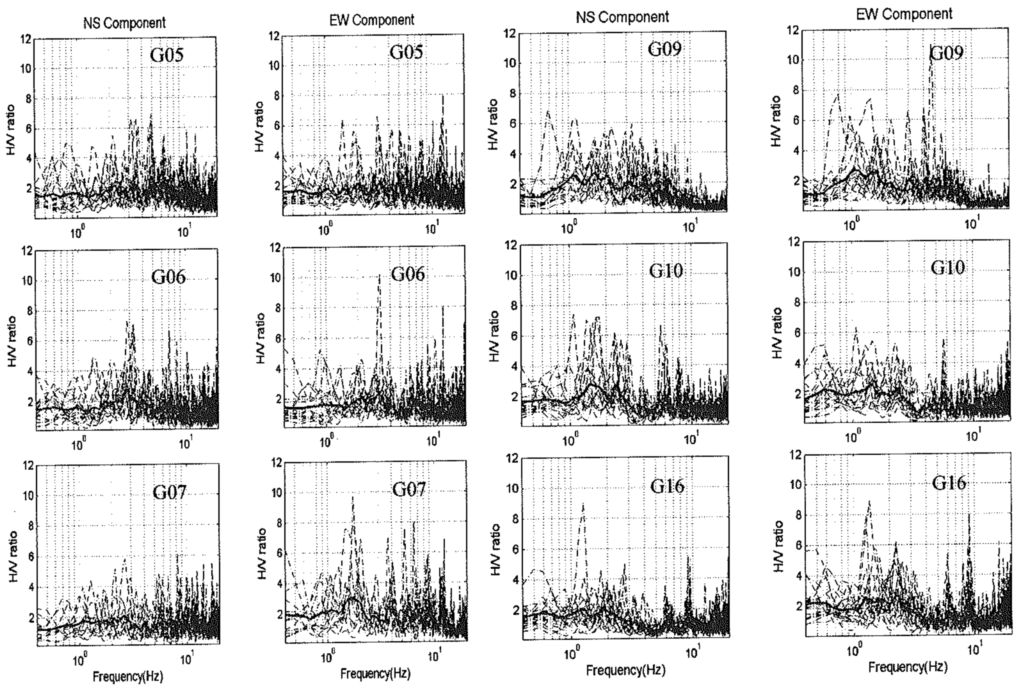


Figure 5: H/V spectral ratios at the sites with good soil conditions

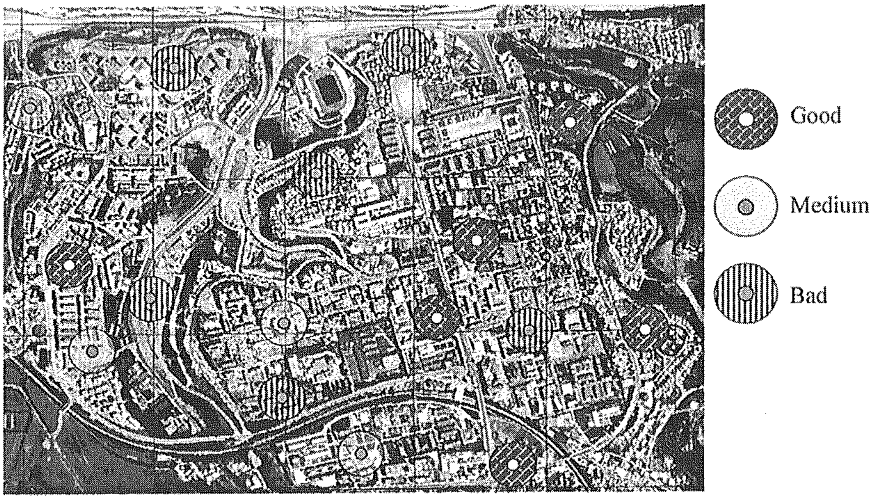


Figure 6: Distribution of soil condition based on the microtremor measurements

STRUCTURAL DAMAGE

The typical construction in Boumerdes city consists of reinforced concrete moment resisting structures with hollow unreinforced brick infill walls. A significant number of the mid-rise RC buildings suffered failure as a result of the May 21, 2003 Boumerdes earthquake. According to the governmental report, the earthquake caused 2,278 deaths, more than 10,000 injured and approximately 180,000 homeless. In Boumerdes city only, 7,400 concrete buildings were destroyed and 7,000 buildings were heavily damaged. **Table 2** shows the statistics of 96,974 damaged buildings surveyed by the National Earthquake Engineering Center (CGS) in Algeria. The damage level was divided into five categories from level 1 (slight damage) to level 5 (partial or total collapse). As it can be seen from the table many residential buildings were damaged.

Table 2. Structural damage level in Algeria and Boumerdes cities

CONSTRUCTION USE	Green		Orange		Red	Total
	Level 1	Level 2	Level 3	Level 4	Level 5	
Residential buildings	181,30	32,352	19,343	11,727	10,183	91,735
Administrative buildings	213	300	184	76	52	825
Schools	420	814	467	286	103	2,090
Hospitals	94	114	44	23	10	285
Sportive and cultural buildings	106	97	90	87	32	412
Commercial buildings	189	193	140	82	137	741
Industrial facilities & hangars	85	153	98	73	66	475
Other (water tanks, etc...)	54	112	110	74	411	411
Total	19,291	34,135	20,476	12,428	10,644	96,974
Percentage (%)	19.90	35.20	21.11	12.82	10.97	100
	55.10		33.93		10.97	100

Source: European-Mediterranean Seismological Center Newsletter, No. 20, September 2003. (http://www.emsc-csem.org/NewsLetter/NewsLetter_20.pdf)

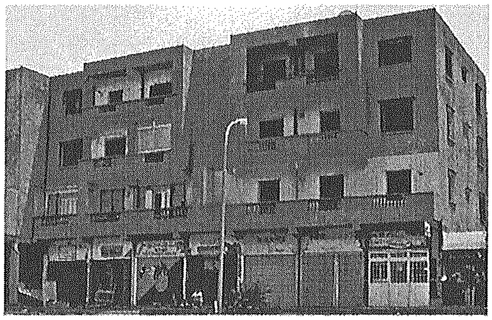
The field survey showed that the damage to RC building structures could be attributed to:

1. Soft story effects

2. Short column effects
3. Poor detailing of structural joints
4. Inadequate transverse reinforcing steel detailing (tie spacing and 90 degree hook)
5. Poor material quality and unsound construction practice.
6. Lateral force was not considered in design
7. Inappropriate anchoring of beam and slab reinforcement.

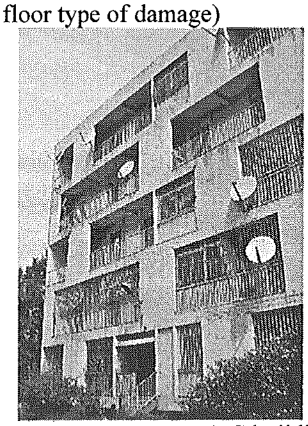
Field survey

A quick inspection of three buildings (**Figure 7**) in Boumerdes city was carried out to investigate the fundamental periods of sample structures in the damaged area. The location of each structure is marked on a post-event satellite image as shown in **Figure 1**. The fundamental period was obtained with microtremor measurements. Since damage increases the fundamental period of structures (Abe et al., 1979), microtremor measurements may be used to identify damage by recognizing changes in the fundamental period. **Table 3** shows the number of stories, building height, the predicted and obtained fundamental period in longitudinal and transverse directions, and damage level based on the National Earthquake Engineering Center (CGS) survey. The approximate values of fundamental period were calculate according to the simplified equation [T=0.02H, where T is a fundamental period in second, H is a building height in meter]. The fundamental period for each building was obtained also from five 40.96 s microtremor measurements for each building. The corresponding five spectra were averaged to obtain the fundamental period as shown in **Figure 8**. The procedure was carried out in both longitudinal and transverse directions. It should be noted that heavy demolition equipments that were in operation near to the observation area might have affected the measurements. It should also be reported that the first observed structure was a four-story buildings with "soft story" type of damage. From **Table 3,** it is clear that the fundamental period for each structure increased, compared with the predicted values, with different levels. This incensement meanly depends on the damage level of each building. The results highlight the possibility of using microtremor measurements to identify damage level by recognizing changes in fundamental period.



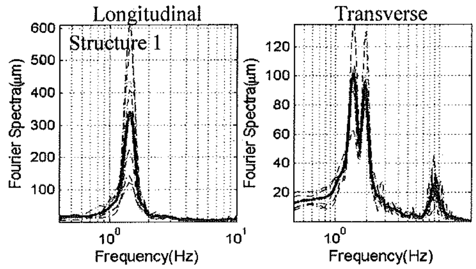
(a) Structure 1 (4-story RC structure with soft floor type of damage)

(b) Structure 2 (Boumerdes University)

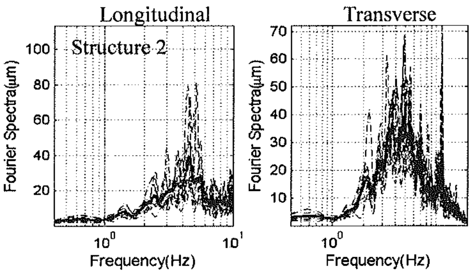


(c) Structure 3 (5-story RC building)

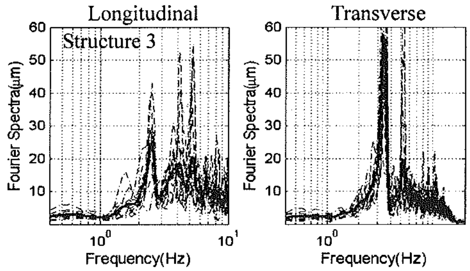
Figure 7: Investigated structures



(a) Structure 1 (4-story RC structure with soft floor type of damage)



(b) Structure 2 (Boumerdes University)



(c) Structure 3 (5-story RC building)

Figure 8: Fourier spectra of the three investigated structures

Table 3. Investigated RC buildings in Boumerdes City

No.	Building name	Location	No. of stories	Height	Predict Period (s) T=0.02H	Fundamental Period (s)		Damage Level
						Longitudinal	Transverse	
1	Residential building	G14	4	15.00	0.30	0.68	0.70	5
2	Boumerdes University	G11	4	25.00	0.50	0.66	0.45	3
3	Residential building	G12	5	15.00	0.30	0.29	0.40	3

DAMAGE TO SILOS (OUTSIDE BOUMERDES CITY)

A reinforced concrete grain silos were inspected in Corso city, close to Boumerdes. The silos were constructed in 1978 and consisted of 45 reinforced concrete cylindrical shafts arranged in five groups of 9 silos each (**Figures 9** and **10**). The approximate dimension of the storage silos is 100 m long x 25 m wide x 40 m high. Although no total collapse was observed as a result of the Boumerdes, Algeria Earthquake, the silos were severally damaged and many of the RC cylindrical shafts developed circumferential flexural cracks at heights between 3 to 12 meters above the ground level as shown in **Figure 11**.

In order to estimate the fundamental frequency of undamaged structures, finite element analysis was performed using SAP 2000 program. A group of 9 reinforced concrete silos, of a 40 m height and 8.25 m diameter of each, were modeled. The thickness of the walls was assumed to be 0.30 m and only the mass of the walls had been considered in the analysis. The calculated fundamental period for the group was 0.24s (4.3 Hz). The dynamic behavior of the damaged RC silos was investigated using microtremor observations. The soil conditions at the silos area were also evaluated.

Results and discussion

At each observed point, microtremor measurements had been performed on the ground surface using two sensors located at a distance of 10 cm and 30 m from the silos. The H/V Fourier spectra for the two sensors' records were determined to evaluate the soil condition (**Figure 12**). From the H/V spectral ratios, it can be followed that soil deposit has an amplification factor approximately equal to 2. Considerable peaks were observed due to the effect of the silos as well as the different soil characteristics.

The spectral ratios of the ($H_{at\ 0.1\ m}$ / $H_{at\ 30\ m}$) had been plotted to give the amplification spectra in longitudinal and transverse directions (**Figure 13**). From **Figure 13**, the fundamental frequencies of each silos group had been obtained in longitudinal and transversal directions and the obtained frequencies were listed in **Table 4**. From **Table 4**, the following conclusions can be drawn:
The fundamental frequency for each observed group varies between 1.05 to 1.45 Hz in the longitudinal direction and between 1.44 to 1.83 Hz in the transverse direction. In longitudinal direction, the variation in the determined fundamental periods of each observed point are agree well with the observed damage level of each silos group (**Figure 10**).
In transversal direction, there is no big difference among the determined fundamental frequencies at P1, P2 and P4 while the highest fundamental frequency had been obtained at P3 which has the lowest damage. The measurements were in a good agreement with damage done by the earthquake. The results again demonstrate the applicability of using microtremor observation for quick investigation of structure damage level.

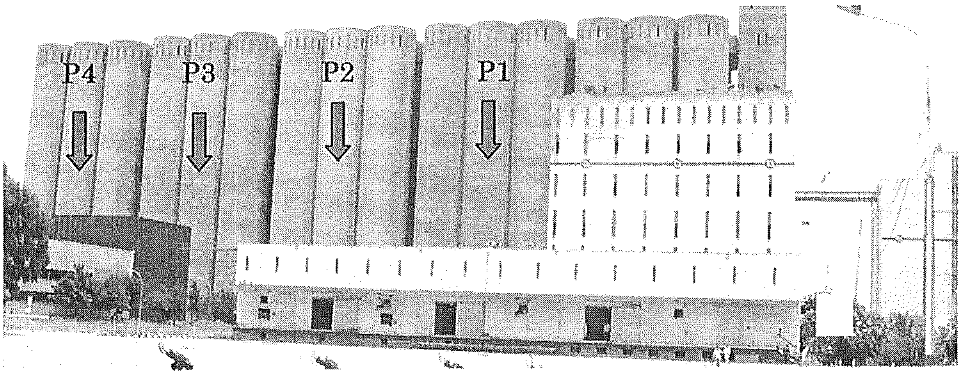


Figure 9 General view for the RC grain silos in Corso city

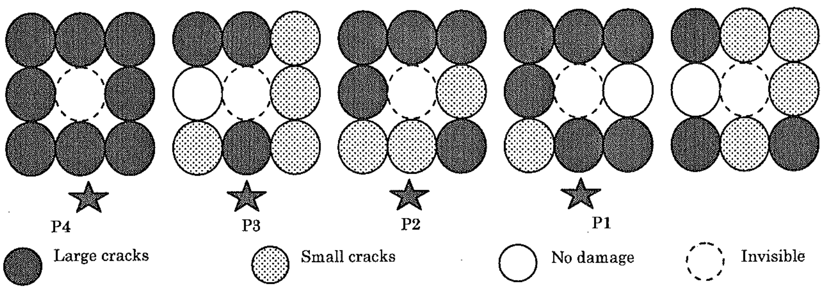


Figure 10 Locations of measurement points and crack levels for each silo

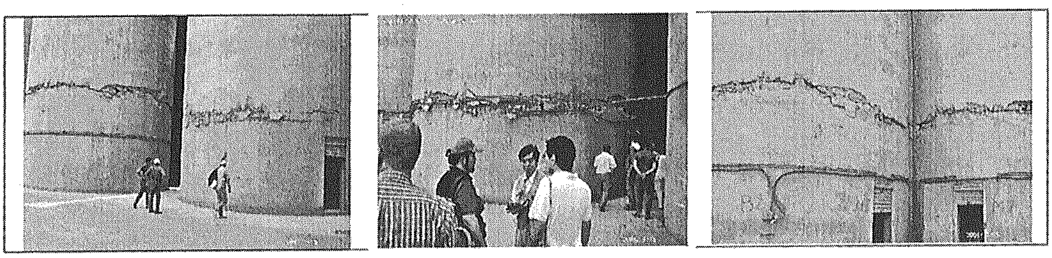
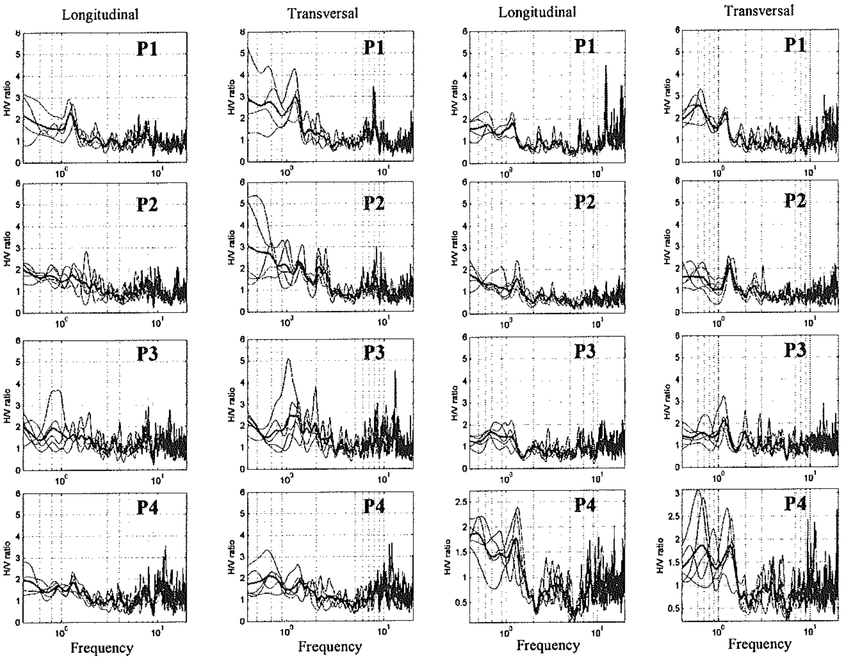


Figure 11 Damage to RC silos showing cracks at different heights



(a) At a distance of 30 m from the silos (b) At a distance of 10 cm from silos

Figure 12 H/V spectral ratios for the observation points

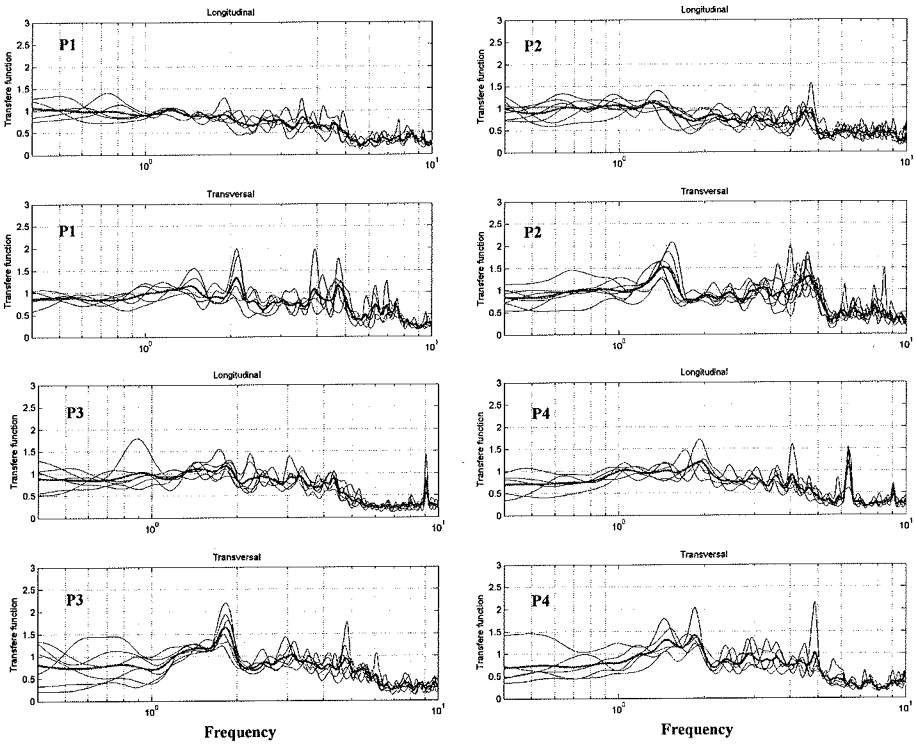


Figure 13 Transfer function for the observation points ($H_{at\ 0.1\ m}/H_{at\ 30m}$)

Table 4. Estimated fundamental frequency of silos at the different observed points

Site Name	Fundamental frequency (Hz)	
	Longitudinal direction	Transverse direction
P1	1.22	1.44
P2	1.33	1.45
P3	1.45	1.83
P4	1.05	1.47

CONCLUSIONS

The Nakamura technique is recognized as a fast and low cost method to evaluate the fundamental frequency and amplification of soil sites. The results obtained in this study concerning 16 sites located in a damaged area in Boumerdes city. The results demonstrate the utility of the method of the H/V ratios of microtremors in the investigation of the site seismic response. Furthermore, the results obtained with microtremors allow the determination of predominant periods of shallow soil which is very important in microzonation studies of urban areas. The soil characteristics and site effects obtained from microtremor measurements were compared with the earthquake damage levels observed in the field survey. A quick inspection had been performed for some damaged buildings to verify the ability of microtremor measurements to characterize damage levels of structures. The results show the fundamental periods for those structures increased with different ratios according to the damage level of each structure.

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