STRONG MOTION DISTRIBUTION AND MICROTREMOR OBSERVATION FOLLOWING THE 21 MAY 2003 BOUMERDES, ALGERIA EARTHQUAKE

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ABSTRACT:

Detailed analysis was conducted for the recorded mainshock across the country during the 21 May 2003 Boumerdes, Algeria earthquake. A remarkable difference has been recorded between neighbour stations. Since local site conditions have a significant effect on the ground motions, and hence on the damage distribution caused by the earthquake, microtremor survey was conducted at several sites of seismic observation stations. In this study, a particular attention is paid to 4 seismic network stations located in the most affected area between Algiers and Boumerdes provinces. Using the microtremor records and the strong motion records from five stations, the effect of soil condition on seismic motion is investigated and the damage distribution caused by this event is explained. The results from this study show that in some stations, the recorded high PGA values were influenced by high-frequency contents. However, in other stations, soil amplification is considered to be responsible for high PGV values. Hence, in order to conduct a further engineering and seismological study, it is highly recommended to conduct an investigation to identify the local soil profile at the seismic stations.

KEYWORDS: the 2003 Boumerdes earthquake, ground motion, microtremor, damage distribution

1. INTRODUCTION

On May 21, 2003, a destructive Mw=6.8 earthquake hit the northern part of Algeria, causing a huge structural and non-structural damages and human casualties. The last report by the Algerian ministers' council (December 12, 2003) deplores that 2,278 deaths and 11,450 injured were claimed by the earthquake. The number of homeless was counted as 250,000, corresponding to 40,000 families. As for the building damage, 17,000 units were demolished and 116,000 were repaired. The resulted direct economic loss was estimated to be 5 billion US dollars (Ousalem and Bechtoula, 2005).

The earthquake was felt inside a 250 km radius zone from the epicenter (Laouami et al., 2006) and provoked the occurrence of liquefaction in the epicentral area. An uplift of coastal line was marked with the average of 0.55m (Harbi et al., 2007; Bouhadad et al., 2004; Meghraoui et al., 2004). In the European side of Mediterranean Sea, tsunamis of about 1.5m high were recorded along the coast of Spain (Alasset et al., 2006). Soon after the event, several international organizations located the 21 May 2003 Boumerdes earthquake. The location given by the Algerian Research Center of Astronomy Astrophysics and Geophysics (CRAAG) was 36.91N, 3.58E. However, the mainshock was relocated at 36.83N, 3.65E with the focal depth of 10 km (Bounif et al., 2004).

The acceleration records of the mainshock were recorded by a number of accelerographs, deployed by the Algerian National Research Center of Earthquake Engineering (CGS). However, several technical problems have occurred during recording the mainshock. The number of free field seismic stations which recorded the mainshock, especially in the severely affected areas, is not sufficient for estimating a detailed strong motion distribution and for analyzing the building damage distribution. Figure 1 shows the location of the mainshock with the seismic observation stations deployed by CGS from which the mainshock was recorded. The mainshock of the 21 May 2003 event was followed by several aftershocks (Bounif et al., 2004), and some of them were measured as magnitude over 5.0.

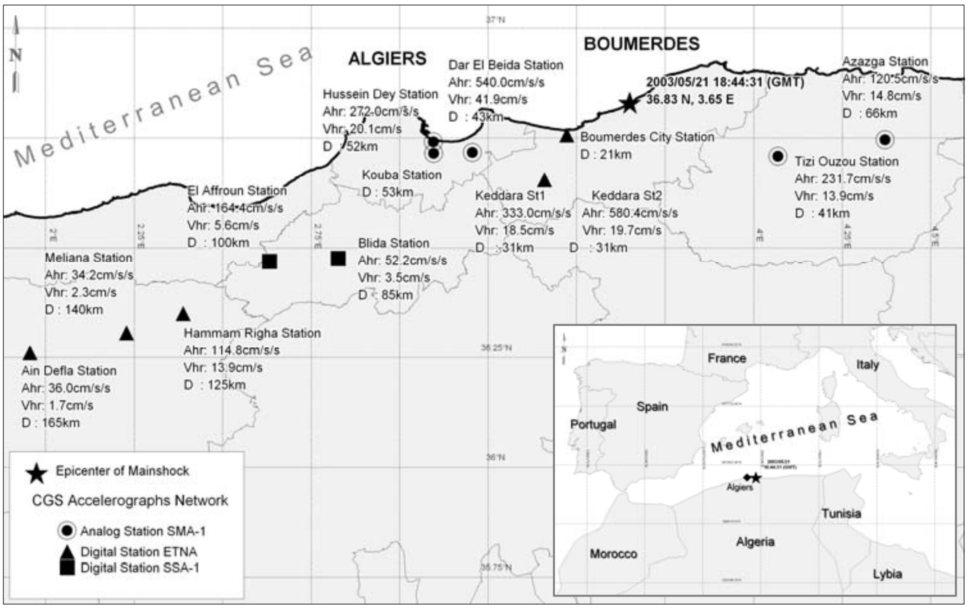


Figure 1 Location of the location (star) of the 2003 Boumerdes earthquake and the CGS accelerograph network that recorded the mainshock. Ahr and Vhr are the maximum resultants of the horizontal acceleration and velocity, respectively. D is the hypocentral distance.

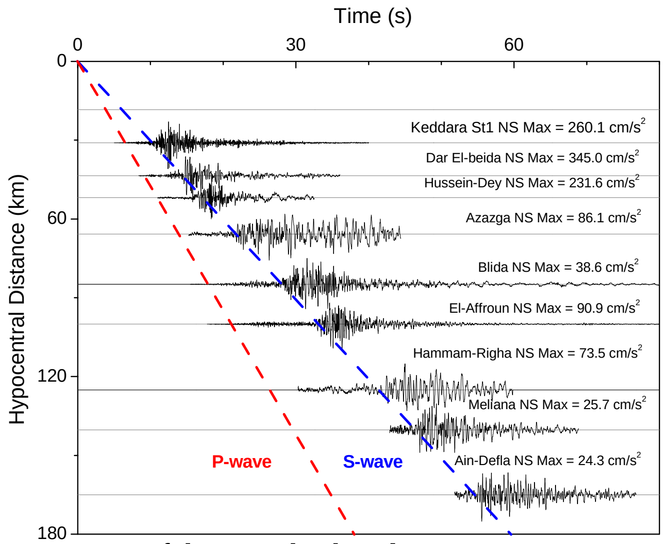


Figure 2 The estimated starting time of the mainshock and seismic wave propagation in the 2003 Boumerdes, Algeria earthquake (NS components).

2. STRONG MOTION RECORDS FROM THE 2003 BOUMERDES EARTHQUAKE

The provinces of Algiers and Boumerdes were classified as most stroked by this event and huge damages and human losses were registered (Bechtoula and Ousalem, 2005). Before the 2003 Boumerdes earthquake, the two provinces were classified as the zone with medium seismic intensity, according to the Algerian seismic code RPA99 (RPA, 1999). But after the event, the both provinces were reclassified as the zone with high seismic intensity in the new seismic code RPA99'03 (RPA, 2003).

For Algiers province with 766 km^2, only two free field records were obtained at Dar El-Beida and Hussein-Dey stations, with hypocentral distances of 43 km and 52 km, respectively. In case of Boumerdes province with 1451 km^2, the only available free field records from the mainshock were those obtained at two Keddara stations, located 31 km away from the hypocenter. The only existing seismic station in Boumerdes city, which is closest to the hypocenter, about 21 km, could not record the mainshock. In fact, many technical problems occurred at several stations while recording the earthquake motions. At some stations, the primary wave of the mainshock was missed, especially for the stations located far from the hypocenter. Figure 2 shows the estimated relative stating time of the earthquake for each station. The starting time of the earthquake at each station is not available because the accelerographs were not equipped with GPS.

Table 1 Peak horizontal acceleration, velocity and displacement of the mainshock of the 2003 Boumerdes earthquake. The maximum values correspond to the NS, EW and the resultant of the two horizontal components.

Station	Hypocentral Distance (km)	Max Acceleration (cm/s^2)			Max Velocity (cm/s)			Max Displacement (cm)		
		NS	EW	Resultant	NS	EW	Resultant	NS	EW	Resultant
Keddara St1	31	260.1	331.5	333.0	12.5	18.5	18.5	5.1	4.9	6.4
Keddara St2	31	345.0	577.0	580.4	11.4	19.6	19.7	3.5	5.6	6.6
Tizi Ouzou	41	192.0	195.2	231.7	6.8	13.9	13.9	1.8	4.6	4.6
Dar El Beida	43	501.1	539.7	540.0	40.6	27.5	41.9	16.8	9.2	18.3
Hussein Dey	52	231.6	269.5	272.0	17.4	18.0	20.1	8.5	9.2	11.4
Azazga	66	86.1	119. 8	120.5	12.0	14.1	14.8	2.9	4.0	4.0
Blida	85	38.6	46.3	52.2	3.5	3.4	3.5	0.8	1.0	1.2
El Affroun	100	90.9	164.0	164.4	5.3	5.0	5.6	0.3	0.4	0.4
Hammam Righa	125	73.5	105.0	114.8	11.9	9.8	13.9	5.3	1.6	5.3
Miliana	140	25.7	31.2	34.2	1.9	2.3	2.3	0.6	1.4	1.5
Ain Defla	165	24.3	33.0	36.0	1.2	1.6	1.7	0.7	0.9	0.9

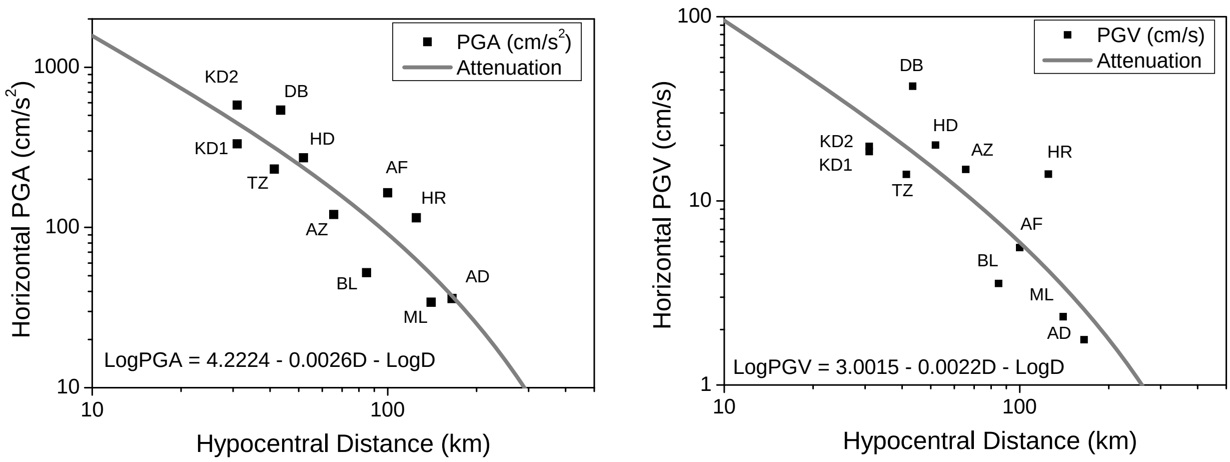


Figure 3 Attenuation law of seismic motion in terms of PGA and PGV

3. ANALYSIS OF RECORDED SEISMIC MOTIONS

A total of 11 free field records from the mainshock were selected for this study. These records were obtained at the seismic stations in a hypocentral distance of 31 km to 165 km (Figure 1, Table 1). According to the implemented documents by CGS, seismic ground motion is recorded in terms of electronic transducers that produce an output voltage proportional to acceleration.

The peak horizontal acceleration (PHA) at each station is seen to be not so proportional to the hypocentral distance. A high PHA value was recorded in a station while in its neighboring stations, the recorded values of

PHAs were not so large, especially for the EW component. However, the dominant direction of the seismic motion is not necessarily consistent with the direction of instruments (EW and NS), and hence, the resultant of the two horizontal components was calculated (Ansary et al., 1995). Table 1 shows the maximum resultant values of the recorded seismic motions. It is well known that the peak acceleration is highly affected by high frequency contents of a seismic motion (Kramer, 1996). The integration of an acceleration record has a similar effect as smoothing or filtering in the frequency domain. This leads to the observation that the velocity time history is less sensitive to the higher-frequency contents of seismic motion.

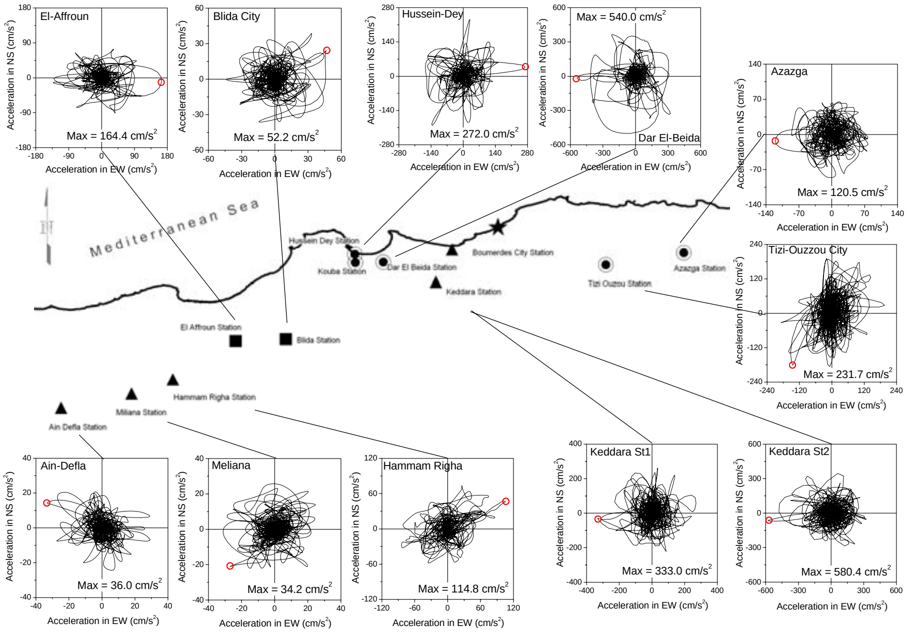
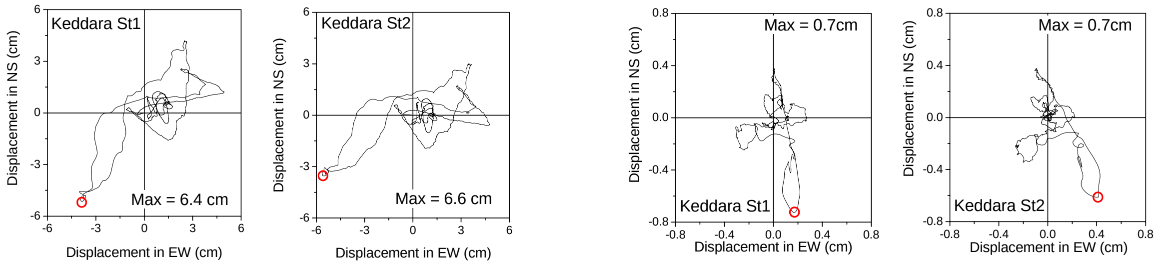


Figure 4 Particle traces of the acceleration records at different seismic stations. Open circle corresponds to the direction of the maximum resultant value.



(a) Mainshock: 21/05/2003 18:44:31 (M=6.8)   (b) Aftershock: 27/05/2003 17:11:29 (M=5.8)

Figure 5 Orbit plots of displacement at Keddara St-1 and St-2. Open circle corresponds to the direction of the maximum resultant value.

For the recorded accelerograms of the mainshock, the velocity and displacement time histories were computed through the integration in the frequency domain using a rectangular filter with low cut-off frequency of 0.05 Hz. Table 1 also presents the peak horizontal velocities and displacements in the two horizontal components and their resultants. Figure 3 shows the attenuation of strong motion in terms of PGA and PGV. The regression curves for attenuation law are also shown (Molas and Yamazaki, 1995).

Figure 4 shows the particle traces of the acceleration records on a horizontal plan at the 11 seismic observation stations. As we can see, none of those stations has shown any predominant direction for acceleration. For the case of the two stations in Keddara, located 31 km from the hypocenter, the displacement orbits at the two stations show the similar shape, but they look to have a rotation angle about the vertical axis. Figure 5 (a) and (b) show the orbit plots of displacement at Keddara St-1 and St-2 for the mainshock and the selected aftershock. The measured difference in angle between the both stations is 20.7 degrees and 20.9 degrees for mainshock and aftershock respectively. Since the distance between the two stations is very small, only 100 m or so, the observed rotation angle may be caused by the orientation error of instrument installation (Yamazaki et al., 1992). The maximum resultant acceleration at Keddara St-1 is 333.0 cm/s^2 but that at Keddara St-2 is 580.4 cm/s^2 (Table 1). However, no such difference is seen for the resultant velocity (18.5 cm/s and 19.7 cm/s) and the resultant displacement (6.4 cm and 6.6 cm) for the stations 1 and 2.

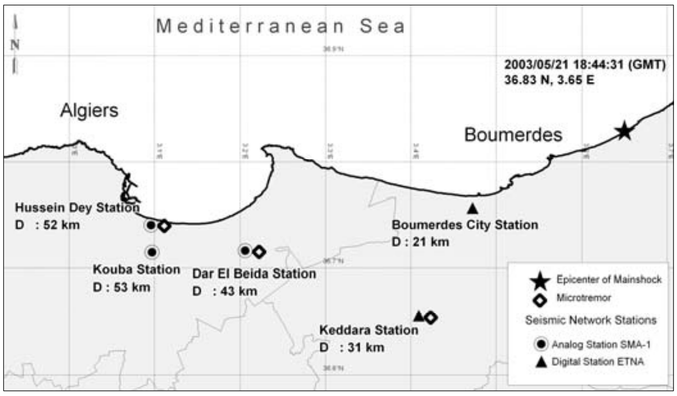


Figure 6 Microtremor measurements at the seismic stations. The selected seismic stations are located in Algiers and Boumerdes provinces, which are most severely affected by the 21 May 2003 Boumerdes earthquake.

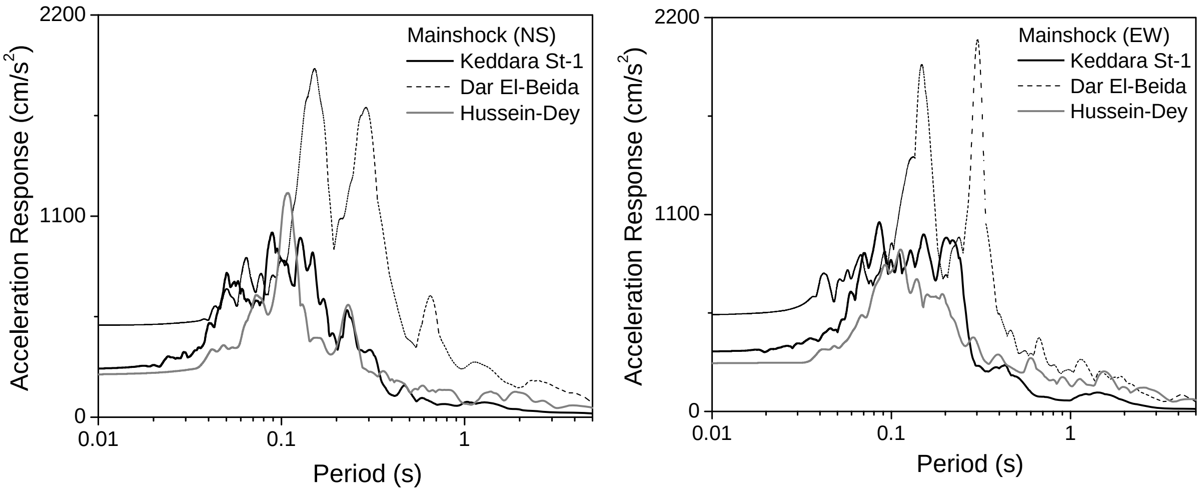


Figure 7 Acceleration response spectra of recorded mainshock at Keddara, Dar El-Beida and Hussein-Dey.

4. COMPARISON OF THE H/V RATIOS OF STRONG MOTION AND MICROTREMOR

In order to evaluate site response characteristics, microtremor measurement was conducted at 4 seismic stations located in Algiers and Boumerdes provinces (Figure 6). Figure 7 shows the acceleration response spectra of recorded mainshock in this area from the stations of Keddara, Dar El-Beida and Hussein-Dey. The average distance between the adjacent stations is about 20 km. The amplitude at Dar El-Beida is quite different from those of the others.

The duration of microtremor observation was set to as 5 minutes, and in order to conduct Fourier analysis, the record was divided into six parts of 50 s duration. The Fourier spectrum was smoothed by Parzen window of 0.4 Hz bandwidth. The horizontal-to-vertical (H/V) Fourier spectral ratio was calculated between one of horizontal (EW and NS) component and the vertical component, as well as the average spectral ratio defined as follows:

$$\left|R_{ave}(T)\right| = \frac{\sqrt{\left|F_{NS}(T)\right|\left|F_{EW}(T)\right|}}{\left|F_{UD}(T)\right|} \tag{1}$$

where R_{ave} is the average H/V spectrum ratio, $F_{NS}(T)$, $F_{EW}(T)$, and $F_{UD}(T)$ are the smoothed Fourier spectra for the two horizontal (NS and EW) and vertical components, respectively.

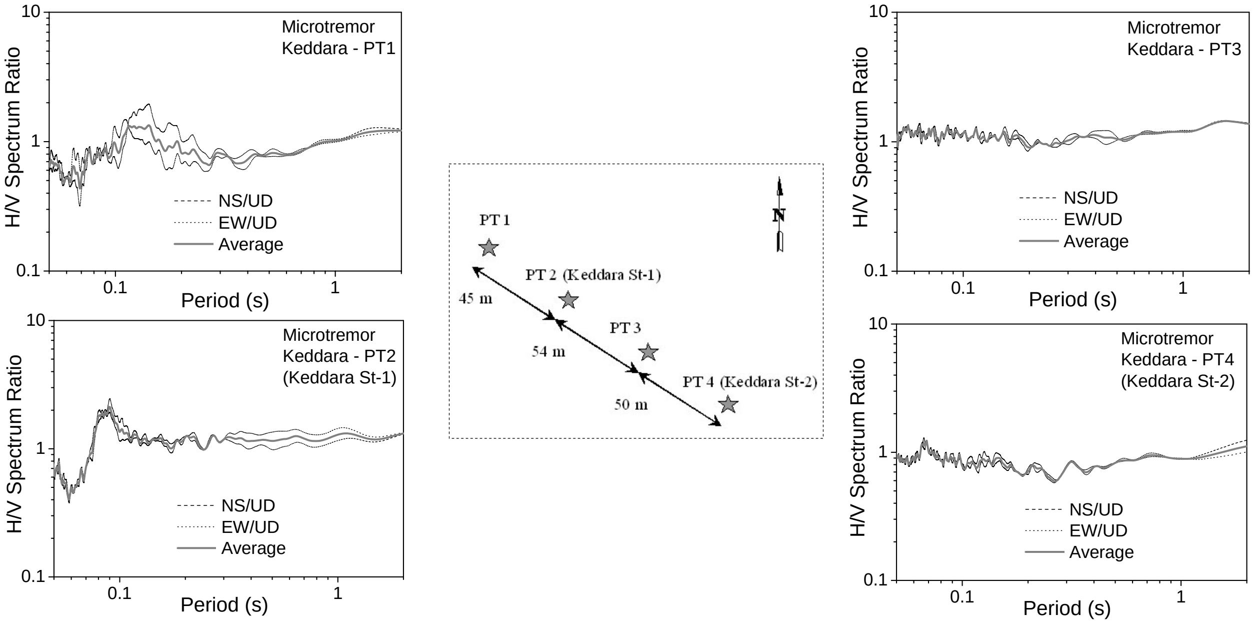
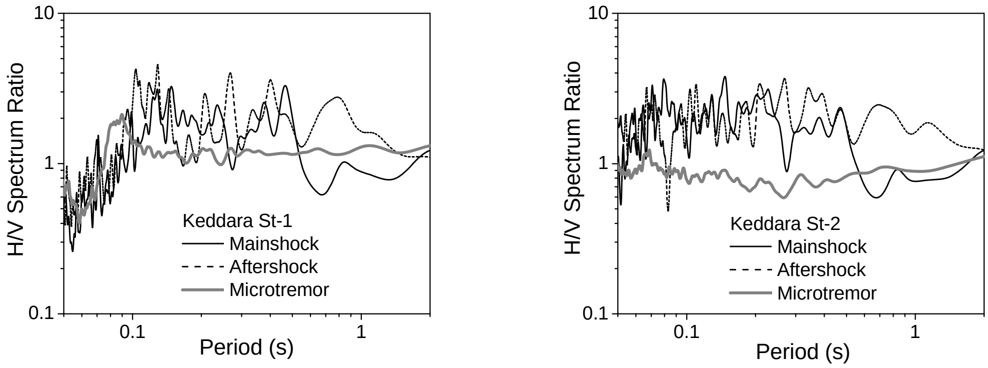


Figure 8 Layout of microtremor measurement points and H/V ratio in Keddara. PT2 and PT4 correspond to Keddara seismic stations 1 and 2, respectively. PT1 and PT3 are the added points for microtremor



(a) Keddara St-1 (b) Keddara St-2

Figure 9 Comparison of H/V spectral ratios between microtremor and seismic motion: Keddara St-1 and Keddara St-2

4.1. Keddara

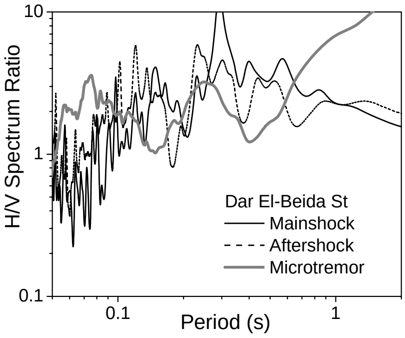
In case of Kaddara, in addition to the two seismic stations, microtremor measurement was conducted at two more points to explain the difference in seismic motion. Thus microtremor was measured at the 4 points with about 50 m distance in Kaddara. Figure 8 shows the microtremor measurement points in Keddara and the H/V Fourier spectral ratios at these points. For Keddara St-1 (PT2), the H/V ratio is seen to be almost flat with a small peak in the period less than 0.1 s, while in Keddara St-2 (PT4), the H/V ratio looks almost flat without peaks. PT1 and PT2 (Kaddara St-1) show the similar H/V behavior with a low peak at a short period. This peak may be due to the presence of soft soil with small thickness. PT3 and PT4 have resemble H/V ratios without a peak. For all the four points, it is clear that the area has a hard soil condition, note that Keddara earth dam is located approximately 400 m from PT4 (Keddara St-2).

According to Yamazaki and Ansary (1997), the amplitude and the shape of H/V spectrum ratio of seismic motion also indicate the site characteristics. A comparison between the H/V spectrum ratios of microtremor and seismic motion is presented in Figure 9 for Keddara stations 1 and 2. At Keddara St-1 the peak period of the H/V spectral ratio gets longer in the order of mainshock, aftershock, and then microtremor, with the similar shape. For Keddara St-2, the H/V ratios are very flat without clear peaks. The selected aftershock corresponds to the event of 27 May 2003 17:11:29 (GMT) with magnitude of 5.8, located at 36.88N, 03.55E. The maximum resultant acceleration and velocity are (123.8 cm/s^2 and 4.4 cm/s) for Keddara St-1 and (150.3 cm/s^2 and 4.2 cm/s) for Keddara St-2.

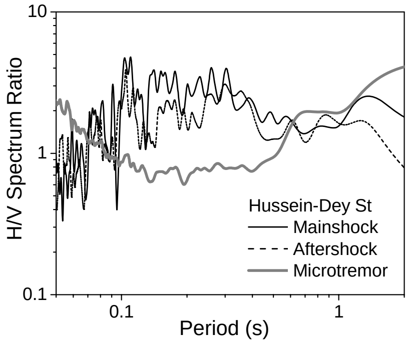
4.2. Dar El-Beida

Dar El-Beida is one of the cities in the province of Algiers affected by the 2003 Boumerdes earthquake. The mainshock recorded by the seismic station in the city, with about 43 km hypocentral distance, has a maximum resultant value of 540.0 cm/s^2 (Table 1). In the city, 2,369 houses were classified as 3 to 4 damage level in European Microseismic Scale (EMS-98) and 66 houses as level 5 damage, which corresponds to very heavy damage or collapse (Azzouz et al., 2005).

According to the H/V ratio of microtremor at this seismic station, the predominant period about 0.25 s with amplification around 3 is observed (Figure 10.a). The soil condition is considered to be softer than other sites, e.g. Kaddara. But this site is not classified as a soft site although the largest strong motion values among neighboring stations were recorded. This observation may be explained by soil amplification, as well as the shortest distance to the source. Comparison of H/V ratios between microtremor and seismic motion for Dar El-Beida City is also shown in the figure. The used aftershock corresponds to the event of 29 May 2003 02:15:07 (GMT) with magnitude of 5.8, located at 36.82N, 03.42E. The maximum resultant acceleration and velocity are 252.0 cm/s^2 and 7.3 cm/s, respectively. The predominant peak is also seen for the mainshock and the aftershock. The peak period gets longer in the order of the mainshock, aftershock and microtremor.



(a) Dar El-Beida Station



(b) Hussein-Dey Station

Figure 10 Comparison of H/V spectral ratios between microtremor and seismic motions at Dar El-Beida and Hussein-Dey.

4.3 Hussein-Dey

Figure 10.(b) shows the H/V ratios of microtremor and seismic motion for Hussein-De city. The H/V ratio of microtremor does not show any predominant peak, and thus this site is considered to be on hard soil. The H/V ratios for microtremor and seismic motion show quite different shapes, which is sometimes the case of hard soil. The selected aftershock was recorded on 16/10/2003 06:38:16 (GMT) with resultant PGA=6.8 cm/s^2 and resultant PGV=0.2 cm/s. The magnitude of this aftershock is 3.6 located at 36.45N 3.63E. The affected buildings by the mainshock in this city are mostly old masonry residential buildings built before 1960's.

5. CONCLUSION

The strong motion records obtained in the 2003 Boumerdes, Algeria earthquake were investigated. The accelerograms show the clear phases of P-wave and S-wave propagations. The attenuation of seismic motion is seen from the source to the recording sites in terms of PGA and PGV. The orbit plots of the recorded motion exhibit the possibility of orientation error between the two closely located stations near Keddara dam. Since the density of the seismic network is not so high and the geotechnical survey data for the area is sparse, microtremor observation was carried out at several seismic stations. The H/V Fourier spectral ratio was calculated and compared for microtremor and seismic records. In Keddara site, microtremor was measured at 4 points and the H/V ratios show the existence of soil layers in two points while not for two other points. The H/V ratios of some seismic stations, e.g. Dar El Beida, show the predominant peak corresponding to site amplification while no clear peak is observed at some seismic stations, e.g. Hussein-Dey, located on hard soil. A further research will be conducted on the relationship between the building damage and site characteristics.

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